HSD-TR-89-009



# UPDATING A DOSAGE-EFFECT RELATIONSHIP FOR THE PREVALENCE OF ANNOYANCE DUE TO GENERAL TRANSPORTATION NOISE

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More than a decade has passed since a relationship between community noise exposure and the prevalence of annoyance was synthesized by Schultz (1978) from the findings of a variety of social surveys. The Air Force has come to rely heavily on this quantitative dosage-effect relationship for predicting aircraft noise-induced annoyance in environmental assessment documents. The effort described in this report updates the 1978 relationship with findings of social surveys conducted since its publication. Although the number of data points from which a new relationship was inferred more than doubled, the newly derived relationship differs little from the ones derived in 1978.

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# Foreword

This report was prepared under Contract F33615-86-C-0530 of the Noise and Sonic Boom Impact Technology (NSBIT) program. The NSBIT program is conducted by the United States Air Force Systems Command, Human Systems Division under the direction of Captain Robert Kull. Mr. Lawrence Finegold served as the contract monitor for this effort.

The work reported herein describes effort completed under Task Order 0012, started 5 October 1987.

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# Executive Summary

More than a decade has passed since a relationship between community noise exposure and the prevalence of annoyance was synthesized by Schultz (1978) from the findings of a variety of social surveys. Environmental planners have come to rely heavily on this quantitative dosage-effect relationship for predicting transportation noise related annoyance. The effort described in this report updates the 1978 relationship with findings of social surveys conducted since its publication. Although the number of data points from which a new relationship was inferred increased greatly, the newly derived relationship differs little from the one derived in 1978.

# 1. Introduction

It has been more than a decade since Schultz (1978) synthesized a relationship between transportation noise exposure and the prevalence of annoyance in communities from the findings of a number of social surveys. Although initially greeted with considerable controversy, the relationship has become the mainstay of assessments of the effects of noise exposure on communities, and has gained widespread currency as the most thorough and well documented dosage-effect relationship available to environmental planners.

One concern expressed at the time of publication of Schultz's synthesis was that it would have a chilling effect on the conduct of further social surveys of noise-induced annoyance, since some believed that agencies which fund such studies might erroneously conclude that the synthesis represented a definitive solution to many of the problems of assessing effects of noise exposure on communities. The abundance of surveys conducted since publication of the synthesis (e.g., Borsky, 1985; Fidell, Horonjeff, Mills, Baldwin, Teffeteller, and Pearsons, 1985; Fields, 1982; Hall and Taylor, 1977; Hall, Brawny, Taylor, and Palmer, 1981; Hede and Bullen, 1982; Rylander, 1977; Schomer, 1983; Sorensen and Hammar, 1983, inter alia) demonstrates that such concerns were unfounded.

In fact, so many measurements have been made of the prevalence of noise-induced annoyance in various communities since publication of the synthesis paper that it is now worth reviewing the dosage-effect relationship derived in 1978 in the light of evidence published since.

## 2. Background

Perhaps the simplest way to make clear the importance of the Schultz synthesis is to describe its historical context. Simple and reliable means for making quantitative predictions of the prevalence of annoyance in communities exposed to aircraft noise prior to publication of Schultz's synthesis were essentially non-existent. Since no widely accepted methods for predicting the prevalence of annoyance had been developed, environmental planners had no recourse other than to cite inconsistent findings of a few first generation social surveys. These social surveys of aircraft noise-induced annoyance followed the introduction of jet transport aircraft into the civil air fleet by only a few years.

In general, these early surveys tended to exaggerate the prevalence of annoyance in communities exposed to aircraft noise. Worse yet, there was so little communication among international agencies sponsoring and conducting these surveys, and so little standardization of survey procedures (e.g., noise measurement practices, questionnaire wording, statistical manipulations and interpretation of findings, etc.) that it was difficult for environmental planners to compare the outcomes of the different studies in any event.

Research on annoyance due to aircraft noise exposure during the 2 decades between the introduction of jet air transports into commercial service and the publication of the original synthesis was marked by a fair amount of non-productive effort, including proliferations of acoustic measurement schemes and notions about intervening variables believed to mediate annoyance. Even as late as the publication of the Levels Document[1] (Environmental Protection Agency, 1974), there was little consensus and no systematic understanding of the nature and magnitude of the aircraft noise problem.

In these unsettled circumstances Schultz focused attention on the similarities rather than the differences among social survey findings. He accomplished this by developing methods for converting noise exposures measured in different units to a common set of units (thereby doing much to establish the utility of Day Night Average Sound Level (DNL) as a general purpose metric of community noise exposure), and by devising ways of comparing annoyance judgments measured on very different response scales. In the process, Schultz provided environmental

[1]The Levels Document was prepared by the Office of Noise Abatement and Control of the Environmental Protection Agency as mandated by the Noise Control Act of 1972 to identify noise exposure levels "adequate to protect public health and welfare with an adequate margin of safety." The document was an influential one which brought together information about a range of noise effects on people and presented a negotiated scientific consensus about threshold levels of the various effects. The Levels Document also consolidated agreement by federal agencies on the Day Night Average Sound Level (DNL) as a general purpose metric of community noise exposure.

planners with their first view of the forest (a dosage-effect relationship between noise exposure and the prevalence of annoyance), rather than the trees (the findings of individual surveys).

The independent variable Schultz chose for the dosage-effect relationship was a cumulative measure of the time integral of noise intensity to which communities are exposed. Reliance on this metric for quantifying noise exposure implies acceptance of the "Equal Energy Hypothesis": that annoyance is predictable from the product of noise duration and intensity. This in turn implies that, within limits, people are indifferent to the manner in which exposure is distributed over time. Thus, use of DNL as a predictor of annoyance implies a strong belief that people are as annoyed by noises of long duration but low level as they are by noises of short duration but compensatingly high level.

The dependent variable Schultz chose for the dosage-effect relationship was a measure of the upper portion of the distribution of self-reported annoyance. The resulting metric, "Percentage Highly Annoyed," is not a statistically sufficient one (i.e., one that reflects the opinions of all social survey respondents). Schultz adopted this centile-based metric in preference to a measure of the central tendency of the distribution of annoyance on several grounds. One reason was that prediction of the percentage of the population annoyed in some consequential degree by noise exposure suited the largely regulatory purposes for which the dosage-effect relationship was prepared.

Another basis for adopting a centile-based metric of annoyance was the considerable likelihood that many people who do not find community noise exposure as measured outdoors to be annoying may not in fact be exposed to such noise. The inadequacies of outdoor, place-oriented measures of community noise exposure are especially clear in the case of neighborhood residents who spend large amounts of time away from home during the day, and for those who do not hear community noise sources in their residences for other reasons.

The methods Schultz developed to compare acoustic measurements and survey responses in like terms inevitably required adoption of a number of assumptions and a good deal of interpretation. Details of these assumptions and interpretations were vigorously challenged at first (cf. Kryter, 1982), but the dosage-effect relationship proved to be so useful that it easily outlived the controversy.

The "Schultz Curve" itself, reproduced in Figure 2-1, is simply a third-order polynomial approximation to a set of data points:

$$\%HA = 0.8553 L_{dn} - 0.0401 L_{dn}^{2} + 0.00047 L_{dn}^{3} \qquad (2-1)$$

This approximation was adopted in preference to a least squares fit in part to force the dosage-effect relationship to predict no annoyance at an exposure level of $L_{dn}$ = 45 dB, in conformity with the EPA Levels Document (EPA, 1974) finding of no effects of noise exposure at this level.

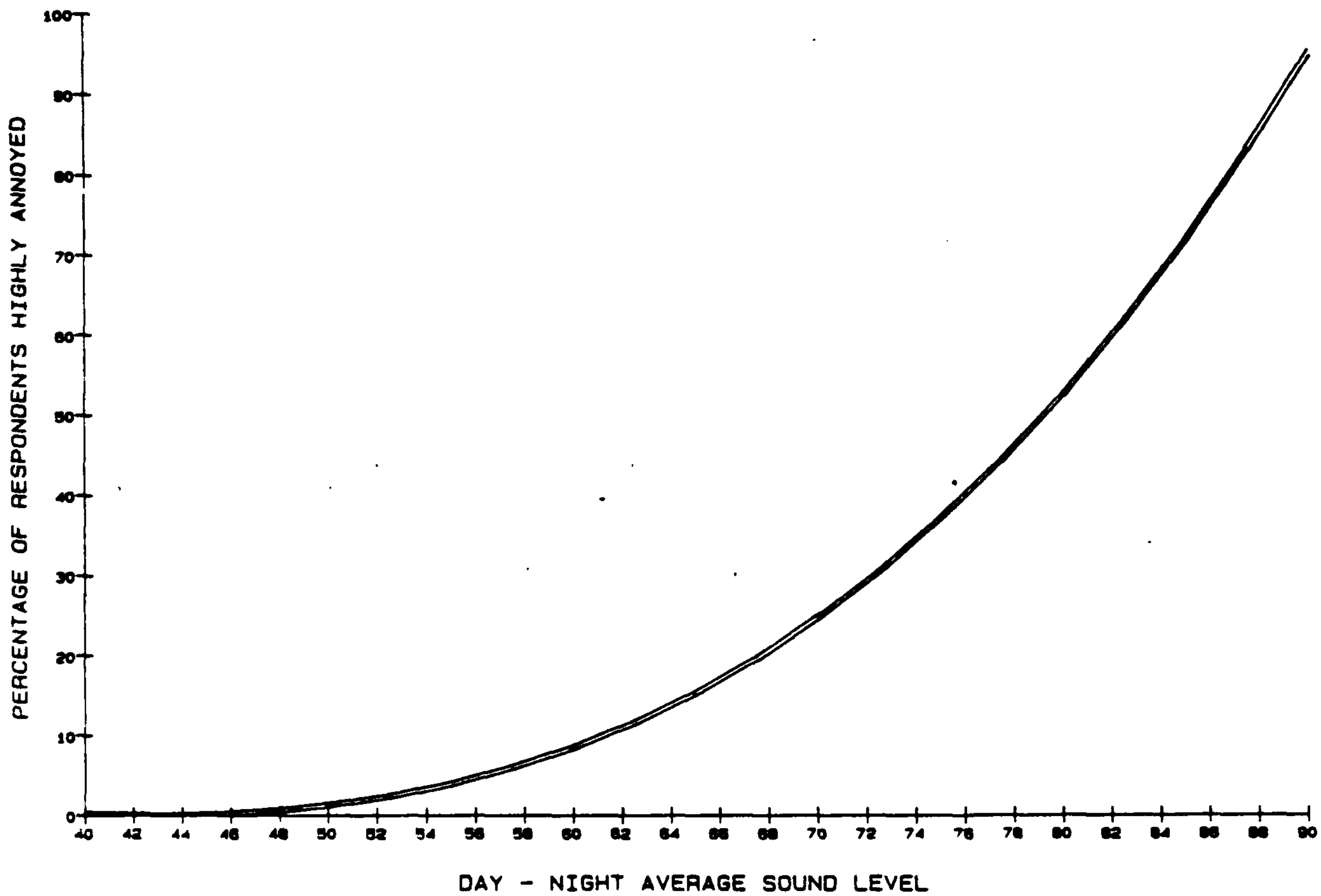


Figure 2-1: Dosage-Effect Relationship Derived in 1978.

# 3. Method

A review of social surveys of the annoyance of general transportation noise published since the preparation of the 1978 Schultz synthesis paper identified a number of studies that were sufficiently similar in design and intent to those considered by Schultz to be useful for comparative purposes. The review concentrated on studies of community reaction to general transportation noise published in English-language professional journals, as well as works published as technical reports. Specifically excluded from this review were laboratory studies of noise-induced annoyance, field studies of community reaction to impulsive noise sources (gunfire, blasting, helicopters, sonic booms, etc.), and studies of community response to other nontransportation sources (e.g., construction).

Information about the identified surveys was entered into a computerized database for subsequent analyses, along with information about the studies considered in the 1978 synthesis paper.

## 3.1 Criteria for Consideration of Data Sets

Five criteria for comparability of studies were adopted:

- At least one questionnaire item had to inquire directly about long term annoyance per se, rather than activity interference or other noise effects from which annoyance might arguably be inferred;
- The noise source under study had to be a transportation noise source, and actual acoustic measurements of noise exposure were strongly preferred;
- Acoustic measurements, if not reported in units of DNL, had to be convertible into such units with reasonable confidence;
- Sample sizes had to be adequate for estimating prevalence of annoyance with reasonable precision; and
- The scale used for quantification of annoyance had to permit identification of numbers of respondents describing themselves as "Highly Annoyed" in a manner comparable to that devised by Schultz (1978).

Repeated efforts were made to contact authors for clarifications if the published account of a study did not contain sufficient information about these matters.

## 3.2 Treatment of Data from Studies Meeting Selection Criteria

A number of the problems of interpretation faced by Schultz in the original synthesis paper resurfaced in the current effort. Consistency of interpretation with the conventions adopted by Schultz was of central concern, since a major goal of the present effort was to preserve comparability of analyses with those that led to the 1978 relationship. For example, the definition of "Highly Annoyed" adopted by Schultz (those respondents whose self-described annoyance fell within the upper 27% - 29% of the response scale, except when category labels unambiguously dictated otherwise) was retained. Likewise, it was necessary to transform noise measurements reported in units other than $L_{dn}$ to units of $L_{dn}$ in several cases.

Each study found suitable for comparison with those considered in the 1978 synthesis paper is described in the next chapter. Table 3-1 summarizes the numbers of data points (paired measurements of noise exposure and prevalence of annoyance) yielded by 11 studies that met the selection criteria. For the sake of completeness, similar information is also included about the "clustering" and "addenda" surveys identified by Schultz (1978)[2].

[2]The "nonclustering" studies discussed by Schultz (1978) are not considered in the present analysis due to the wide scatter and variability exhibited by these surveys. The reader is referred to Schultz (1978) page 383 for a detailed explanation of why these studies were omitted from the 1978 dosage-response relationship.

**Table 3-1: Summary of Social Surveys Reviewed.**

| *Mnemonic* | *Authors(s)* | *Number of Data Points* |
|---|---|---|
| *1978 Clustering Surveys:* | | |
| (1) FRENCH AIRCRAFT | Alexandre, 1970 | 6 |
| (2) SECOND HEATHROW AIRPORT | MIL Research, 1971 | 20 |
| (3) FIRST HEATHROW AIRPORT | McKennell, 1963 | 10 |
| (4) LONDON TRAFFIC | Langdon, 1976 | 24 |
| (5) MUNICH AIRCRAFT | Rohrman et al., 1974 | 27 |
| (6) PARIS STREET | Aubree et al., 1971 | 8 |
| (7) FRENCH RAIL | Aubree, 1975 | 5 |
| (8) SWEDISH AIRCRAFT | Rylander et al., 1972 | 17 |
| (9) SWISS ROAD | Grandjean et al., 1973 | 6 |
| (10) SWISS AIRCRAFT | Grandjean et al., 1973 | 12 |
| (11) USA 24 SITE | Fidell, 1978 | 24 |
| (12) LOS ANGELES AIRPORT | Fidell and Jones, 1975 | 2 |
| | | *Subtotal:* 161 |

Table 3-1: Summary of Social Surveys Reviewed (continued)

| *Mnemonic* | *Authors(s)* | *Number of Data Points* |
|---|---|---|
| *1978 Addenda/New Surveys: (studies which are marked with an asterisk are addenda studies)* | | |
| (1) U.S. AIRBASE | Borsky, 1985 | 25 |
| (2) ANTWERP STREET* | Myncke et al., 1977 | 31 |
| (3) BRUSSELS STREET* | Myncke et al., 1977 | 23 |
| (4) BURBANK AIRPORT | Fidell et al., 1985 | 20 |
| (5) CANADIAN ROAD* | Hall and Taylor, 1977 | 14 |
| (6) DANISH STREET* | Relster, 1975 | 28 |
| (7) BRITISH RAIL | Fields and Walker, 1982 | 11 |
| (8) AIRCRAFT/TRAFFIC | Hall et al., 1977 | 21 |
| (9) ORANGE COUNTY AIRPORT | Fidell et al., 1985 | 12 |
| (10) AUSTRALIAN AIRCRAFT | Hede and Bullen, 1982 | 42 |
| (11) TRAMWAY/TRAFFIC | Rylander, 1977 | 12 |
| (12) DECATUR AIRPORT | Schomer, 1983 | 4 |
| (13) SWEDISH RAILROAD | Sorensen and Hammar, 1983 | 15 |
| (14) WESTCHESTER AIRPORT | Fidell et al., 1985 | 8 |
| (15) DANISH RAILROAD | Andersen et al., 1982 | 26 |
| | | *Subtotal:* 292 |
| | | *TOTAL:* 453 |

# 4. Results

## 4.1 Analyses of Data from Individual Studies

This chapter describes the social surveys which satisfied the selection criteria noted earlier. Appendix A contains raw data from these surveys.

### 4.1.1 Australian Aircraft (Hede and Bullen, 1982; 3575 Interviews)

Hede and Bullen report a conventional social survey of the annoyance of aircraft noise. Noise levels were reported in units of $L_{dn}$ for field measurements made at various locations around the commercial airports at Sydney, Perth, Adelaide, Melbourne, and the Royal Australian Air Force Base at Richmond. Personal interviews were conducted with 45 to 115 respondents per site. The physical measurements used in the present analysis are reported in Hede and Bullen's Tables 3.3 and D.9 and Figure 6.4. Twenty-four hour noise measurements were made for approximately 2 weeks per site. These values were then compared with existing Noise Exposure Forecast (NEF) contours for accuracy.

The percentages of respondents highly annoyed were tabulated from responses to Questionnaire Item 36 by the authors (Bullen, 1988). The item was worded "How would you describe your 'general feelings' about the aircraft noise in this neighborhood?" Respondents were constrained to select one of the following categories: (1) Highly Annoyed, (2) Considerably Annoyed, (3) Moderately Annoyed, (4) Slightly Annoyed, or (5) Not At All Annoyed.

This data set contains a total of 42 paired values of measured noise levels and percentages of respondents highly annoyed. Only those respondents describing themselves as "Highly Annoyed" were considered highly annoyed for present purposes to conform with the convention adopted by Schultz (1978, p. 381) for dealing with named response categories. Counting respondents selecting the upper 20% of the response scale as Highly Annoyed underestimates the prevalence of annoyance in this survey with respect to that reported in other surveys in which response categories were unnamed, or which otherwise permitted counting responses made in the upper 27 - 29% of the response scale.

95% confidence intervals were calculated for the estimated percentages of respondents highly annoyed at each interviewing site by assuming that the self-reports of annoyance in the categories "Highly Annoyed" and all other categories were binomially distributed, as follows:

$$1.96\sqrt{PQ/n} \qquad (4\text{–}1)$$

where: P = proportion of respondents highly annoyed, Q = proportion of respondents not highly annoyed, and n = number of respondents per site.

Figure 4-1 displays the 95% confidence intervals for the data points reported by Hede and Bullen in relation to the dose-response curve synthesized by Schultz (1978). The data are in reasonable agreement with the original synthesis curve.

### 4.1.2 Aircraft - Traffic Comparison (Hall et al., 1981; 673 Interviews)

This social survey compared the annoyance from aircraft noise to the annoyance of road traffic noise at 9 sites around Toronto International Airport. Interviews were conducted with 10 to 180 respondents per site. Noise levels were reported in units of $L_{dn}$. The data analyzed for present purposes are those reported in Table 3 (road traffic) and Table 4 (aircraft) of Hall et al. (1981).

Data for road traffic noise were collected at one location per site by automated equipment during 24-h weekday periods. Aircraft noise exposure was predicted by the Integrated Noise Model software. Control tower records for 1977 were used as the source of operational information for the predictions.

Hall et al. elicited judgments of the annoyance of transportation noise sources with a direct question ("How do you rate each of the sounds you have mentioned?") and a bipolar response scale composed of the following categories: (1) Extremely Agreeable, (2) Moderately Agreeable, (3) Considerably Agreeable, (4) Slightly Agreeable, (5) Neutral, (6) Slightly Disturbing, (7) Moderately Disturbing, (8) Considerably Disturbing, and (9) Extremely Disturbing.

Totals of 9 data points for aircraft noise and 12 data points for traffic noise were reported. Hall et al. suggested that "...the appropriate cutoff point for high annoyance on the response scale is between moderately and considerably disturbing...." This criterion represents the top 2 of the 9 response categories of the bipolar scale. If the "Neutral" category is considered to be equivalent to "Not at All Annoyed," however, Hall et al. in effect counted the top 40% of a 5 point scale. Thus the authors' criterion overestimates the percentage of respondents highly annoyed relative to the percentages counted by the criteria adopted for the 12 clustering surveys.

Figure 4-2 shows 95% confidence intervals for both the aircraft and traffic noise data. The traffic noise data show good agreement with the original synthesis curve, while the aircraft data lie considerably above the curve.

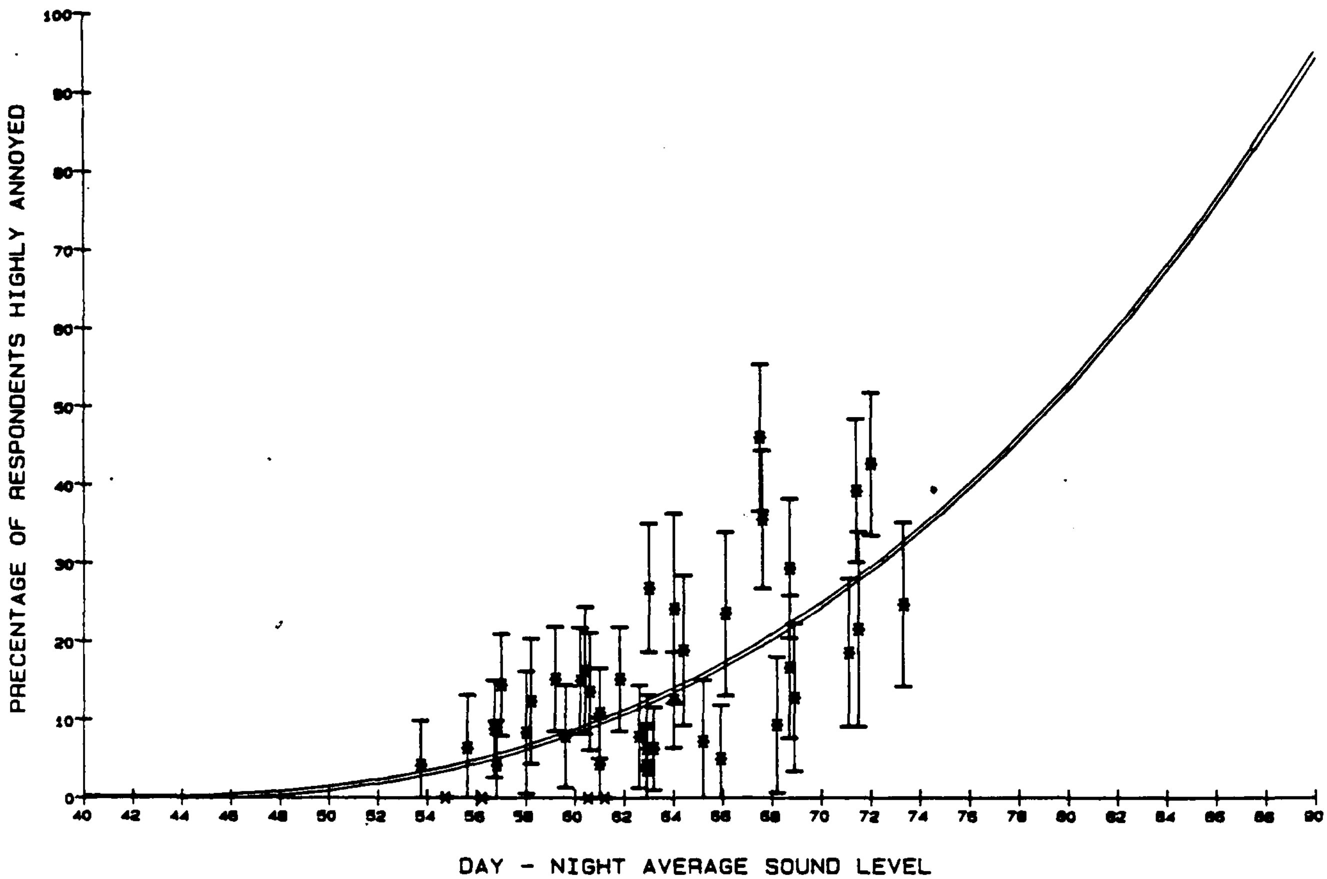


Figure 4-1: Relationship of Data from Australian Aircraft Study to 1978 Synthesis Curve.

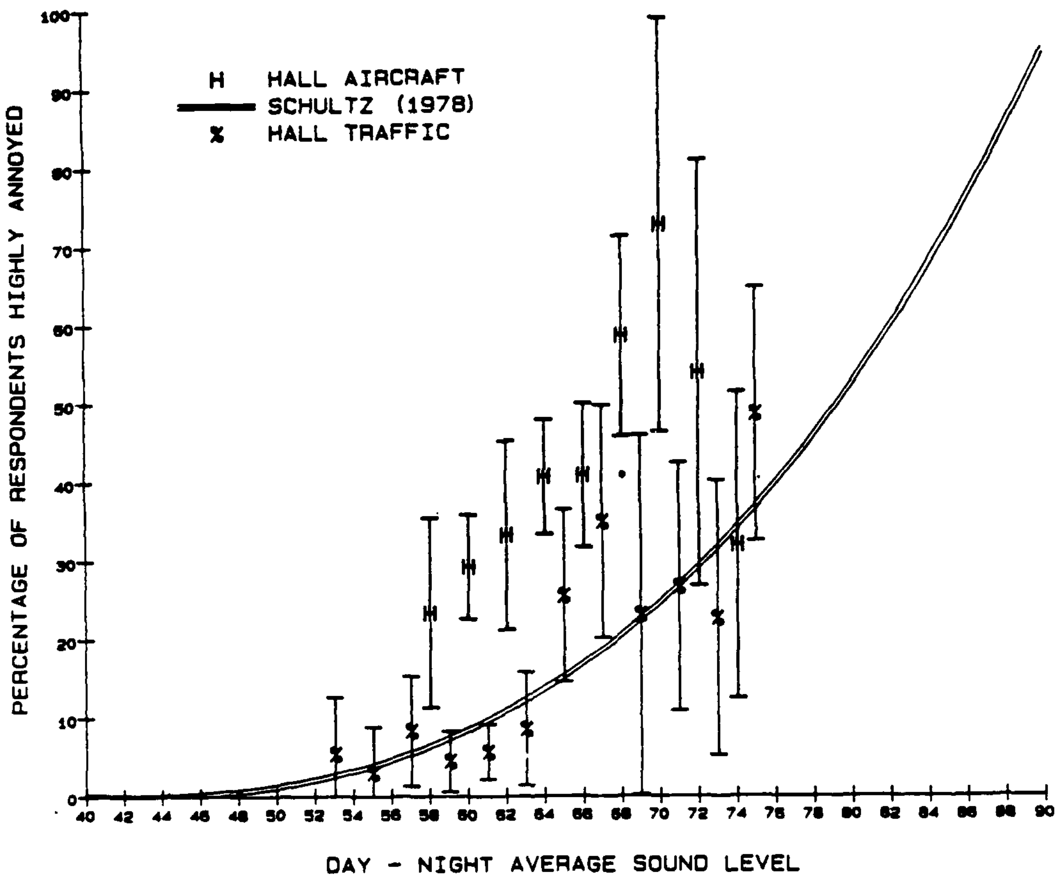


Figure 4-2: Relationship of Data from Aircraft-Traffic Comparison Study to 1978 Synthesis Curve.

### 4.1.3 Burbank Airport Survey (Fidell et al., 1985; 5041 Interviews)

Fidell et al. describe a social survey of aircraft noise annoyance involving multiple rounds of interviews in the vicinity of a mixed-use civil airport (reported as "Study One" in Fidell et al. (1985)) at which noise levels changed considerably over time due to changing runway use patterns. Noise levels were monitored continuously for a week prior to interviewing at multiple microphone positions within the boundaries of each site, and calibrated against exposure gradients from aircraft noise exposure contours. Five rounds of face-to-face and telephone interviews were conducted with 220 to 330 respondents per site. Table 2 of Fidell et al. (1985) presents the annoyance and noise data for 5 rounds of interviews in 4 airport neighborhoods. The percentage of respondents highly annoyed was derived from responses to Questionnaire Item 4, which asked respondents if they had been (1) Not At All Annoyed, (2) Slightly Annoyed, (3) Moderately Annoyed, (4) Very Annoyed, or (5) Extremely Annoyed by the noise of aircraft over the past year.

Twenty data points resulted from this assessment of long term noise exposure. (Another questionnaire item that solicited judgments of the annoyance of aircraft noise exposure over the past week was not considered for present purposes to preserve comparability with the time scales of other surveys.) Respondents describing themselves as "Extremely Annoyed" or "Very Annoyed" were considered to be highly annoyed. This definition of annoyance encompasses 40% of the response scale, somewhat more than the 27% - 29% of the scale typical of surveys considered in the original synthesis. To conform with prior practice, however, the category "Very Annoyed" was also included in the definition of "High Annoyance" simply because its name strongly suggests as much.

Figure 4-3 displays 95% confidence intervals for the data points. Many of the data points lie considerably above the original synthesis curve. Fidell et al. (1985) speculate about a number of differences between the circumstances of noise exposure at this mixed use airport and larger airports, which might account for the lack of agreement.

### 4.1.4 Orange County Airport (Fidell et al., 1985; 3103 Interviews)

This social survey was reported as "Study 2" in Fidell et al. (1985). Noise exposure measurements were made by the monitoring system installed at Orange County Airport. The data were energy-averaged over week-long intervals from 6 microphone positions and were compared with known aircraft noise contours to estimate area-weighted noise exposure levels. These sites were part of the airport's installed noise monitoring system. Face-to-face and telephone interviews were conducted with 200 to 330 respondents per site. Table 4 of Fidell et al. (1985) summarizes the long term annoyance data produced in 4 rounds of interviews in 3

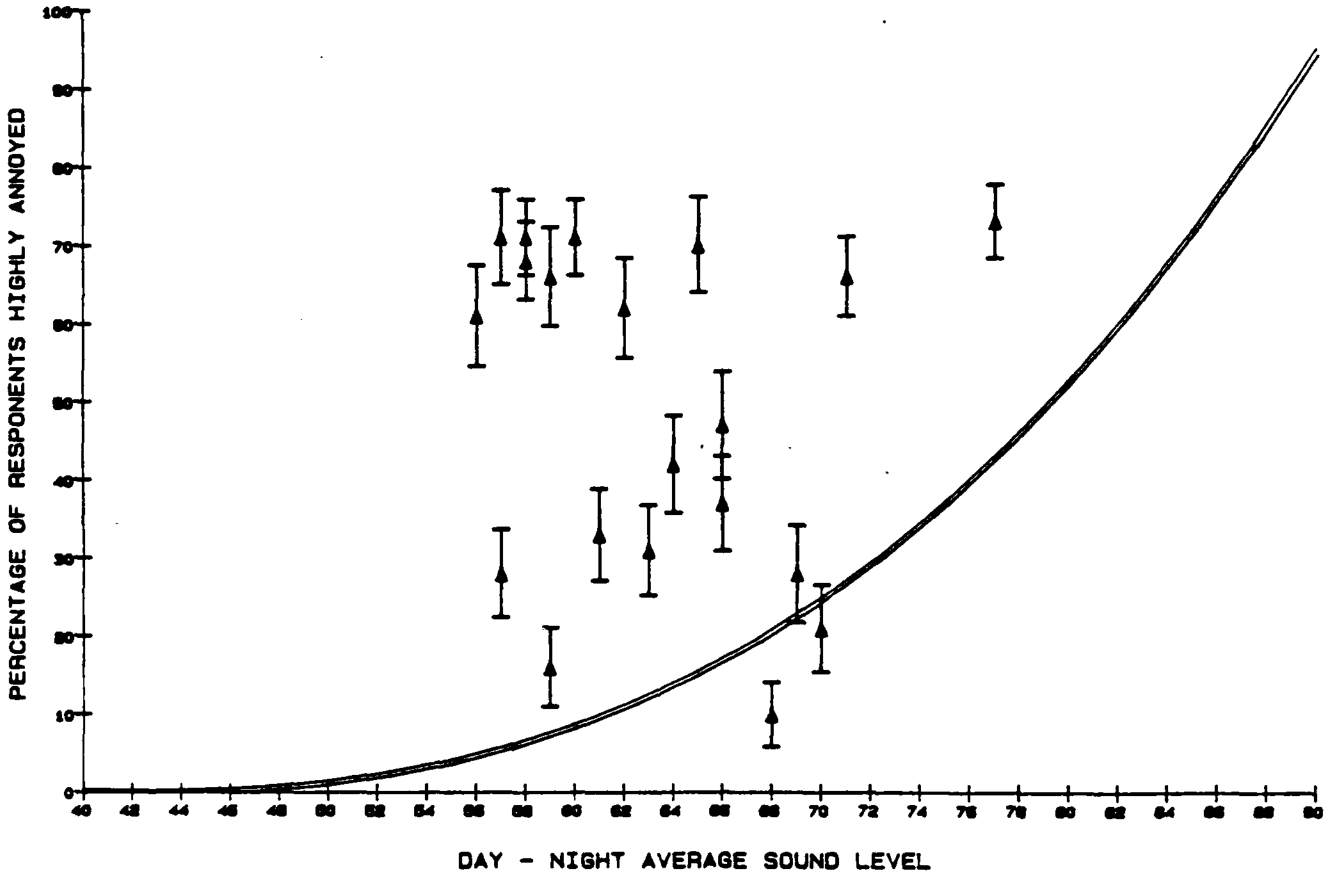


Figure 4-3: Relationship of Data from Burbank Airport Study to 1978 Synthesis Curve.

interviewing areas in airport environs. The percentage of respondents highly annoyed was compiled from responses to Questionnaire Item 5, which asked respondents "While you've been at home over the past year, since last (season of year), have you been bothered or annoyed by the noise from large airliners?" The named categories for the response scale were : (1) Not At All Annoyed, (2) Slightly Annoyed, (3) Moderately Annoyed, (4) Very Annoyed, or (5) Extremely Annoyed. Respondents describing themselves as Very or Extremely Annoyed were counted as highly annoyed. This definition of annoyance encompasses 40% of the response scale, somewhat more than the 27% - 29% of the scale typical of surveys considered in the original synthesis. To conform with prior practice, however, the category "Very Annoyed" was also included in the definition of high annoyance simply because its name strongly suggests as much.

Twelve paired values of percentages of respondents highly annoyed and measured sound levels were reported. These data points may be seen in Figure 4-4. Like the data points of the Burbank Airport study, these data points also lie considerably above the 1978 dosage-effect relationship.

### 4.1.5 Tramway and Traffic Survey (Rylander et al., 1977; 464 Interviews)

Rylander et al. report a survey focused on differences in respondents' reactions to tramway and city traffic noise. Interviews were conducted with approximately 75 respondents at each of 12 sites in Gothenburg, along streets supporting mixed motor vehicle and tramway traffic. Noise measurements were collected on tape recorders at 1-h intervals during afternoons, for later analysis by a statistical distribution analyzer. Specifics of the period of time over which these measurements were taken were not reported.

Noise levels reported in units of 24-h $L_{eq}$ for both tramway and traffic noise were converted to $L_{dn}$ values by taking the average of 2 different conversion procedures. The conversion equation for the first method (Galloway, 1977) was:

$$L_{dn} = L_{eq} + 3.38 dB \qquad (4\text{–}2)$$

The conversion equation for the second method (Schultz, 1978) was:

$$L_{dn} = 1.13 L_{eq} - 4.9 dB \qquad (4\text{–}3)$$

The differences between the conversions ranged from .3 to .8 dB.

Respondents were provided with 3 response categories from which to select an answer to the question "Are you annoyed by tramway or traffic noise?" (1) A Little Annoyed, (2) Rather Annoyed, and (3) Very Annoyed. Rylander et al. (1977) present the noise exposure and response

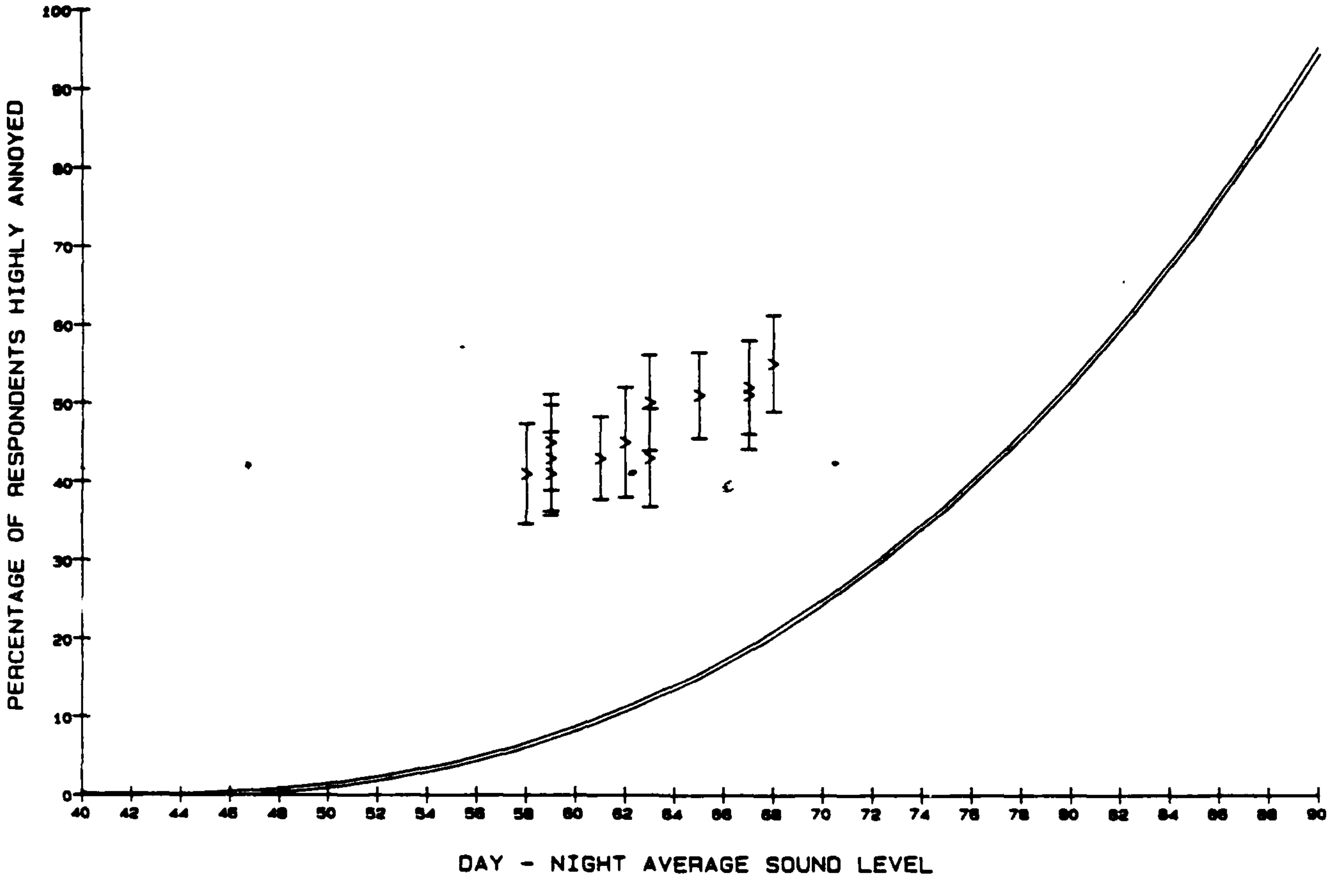


**Figure 4-4:** Relationship of Data from Orange County Airport Study to 1978 Synthesis Curve.

data in Tables 1 and 2 for respondents who described themselves as "Very Annoyed." Respondents considered to be very annoyed by Rylander et al. (1977) were counted as highly annoyed for present purposes. Assuming that nonresponse can be construed as a 4th (not annoyed) category, this definition of high annoyance includes 25% of the response scale, slightly underestimating the percentage highly annoyed by the preferred definition (27%-29% of the response scale) of the 1978 synthesis.

A total of 12 data points consisting of noise levels and percentages of respondents highly annoyed (6 for tramway and 6 for traffic) were reported by Rylander et al. Figures 4-5 and 4-6 display the 95% confidence interval in relation to the Schultz Curve for both tramway and traffic noise, respectively. Although several of the data points lie close to the 1978 dosage-effect relationship, several lie below the curve.

#### 4.1.6 Decatur Airport (Schomer, 1983; 231 Interviews)

Schomer (1983) reports a survey of attitudes toward aircraft noise conducted near Decatur, Illinois Airport. Noise measurements, made in units of $L_{dn}$, were compared against exposure levels predicted by Integrated Noise Model Version 2.6. Personal interviews were conducted at 4 sites with 22 to 99 respondents per site.

Questionnaire Item 7a inquired about noises heard at home that respondents preferred not to hear. For each undesired noise source heard in the home, Questionnaire Item 7f asked respondents to rate their annoyance using the following scale: (1) Extremely Annoyed, (2) Very Much Annoyed, (3) Moderately Annoyed, or (4) Slightly Annoyed. Schomer considered respondents who described themselves as "Very Much Annoyed" or "Extremely Annoyed" as highly annoyed. Schomer presents noise source and response data in his Figure 3 and Table 4 for respondents he considered highly annoyed.

Respondents who spontaneously mentioned some type of noise annoyance were considered to be at least "slightly annoyed" by the noise source. It is assumed that respondents were "Not at All Annoyed" by noise sources that escaped mention, yielding a 5 category response scale.

Schomer's study yielded 4 paired observations of measured noise levels and percentages of respondents highly annoyed. As shown in Figure 4-7, these data points lie in close proximity to the original synthesis curve.

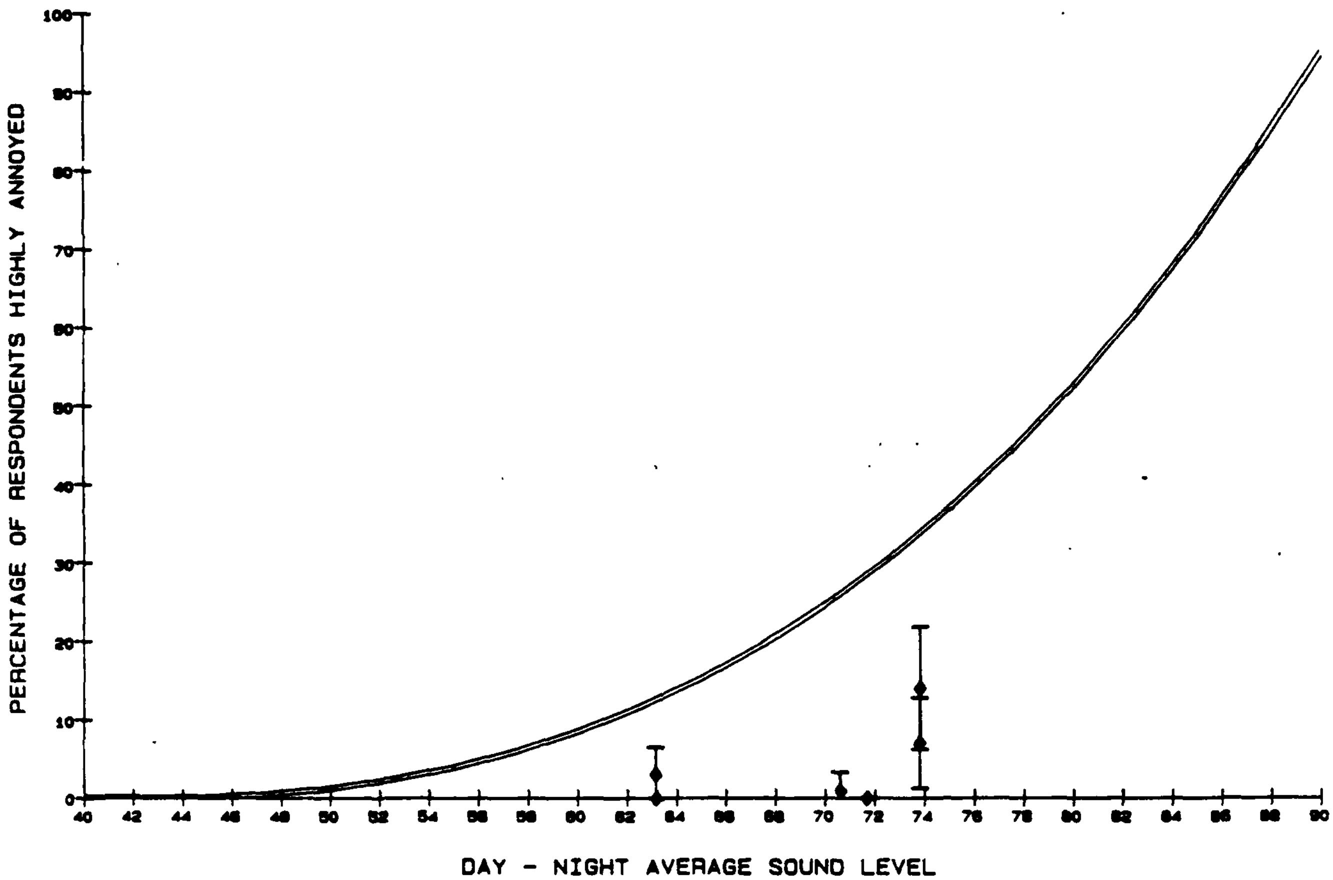


Figure 4-5: Relationship of Tramway Data from Tramway and Traffic Study to 1978 Synthesis Curve.

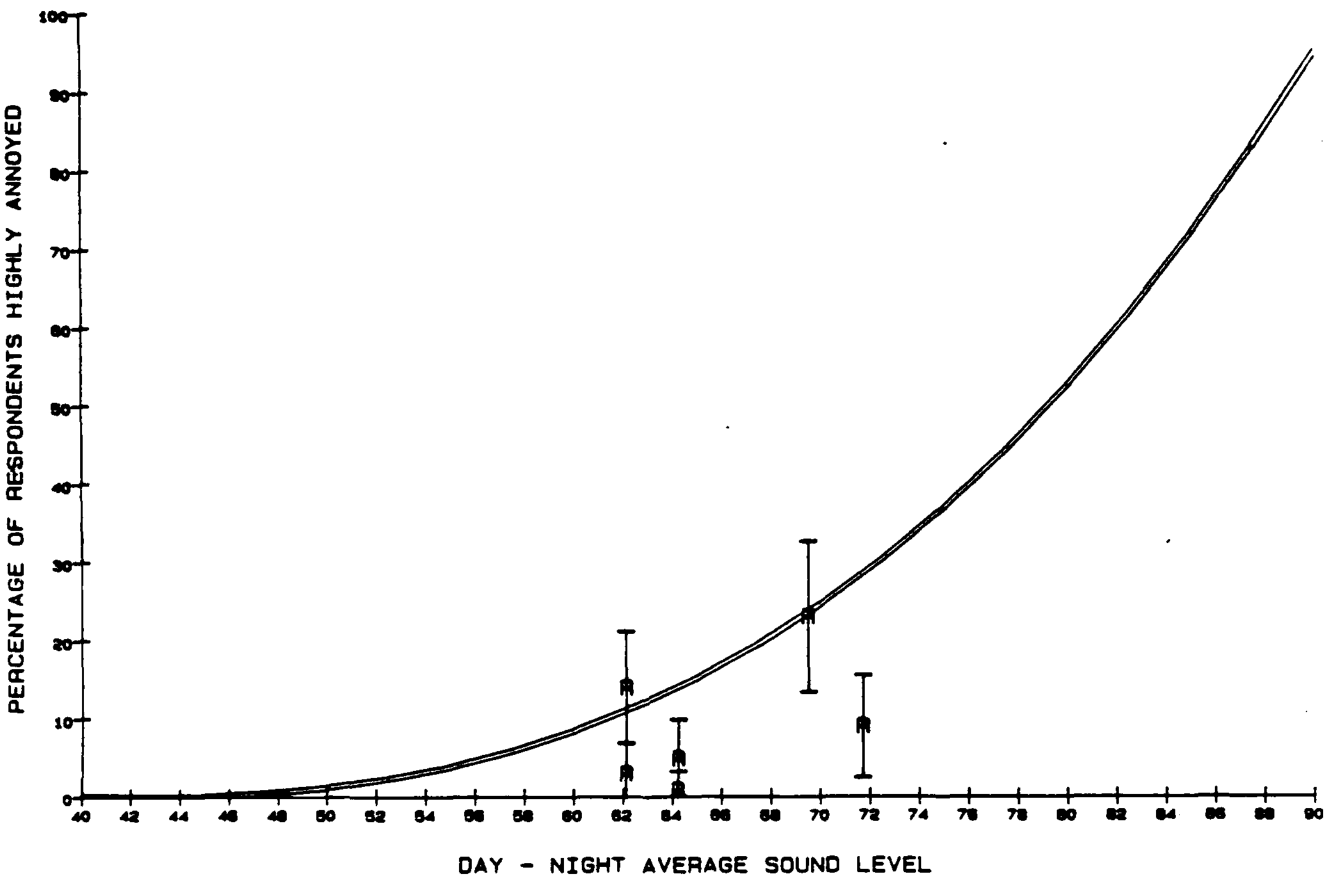


Figure 4-6: Relationship of Traffic Data from Tramway and Traffic Study to 1978 Synthesis Curve.

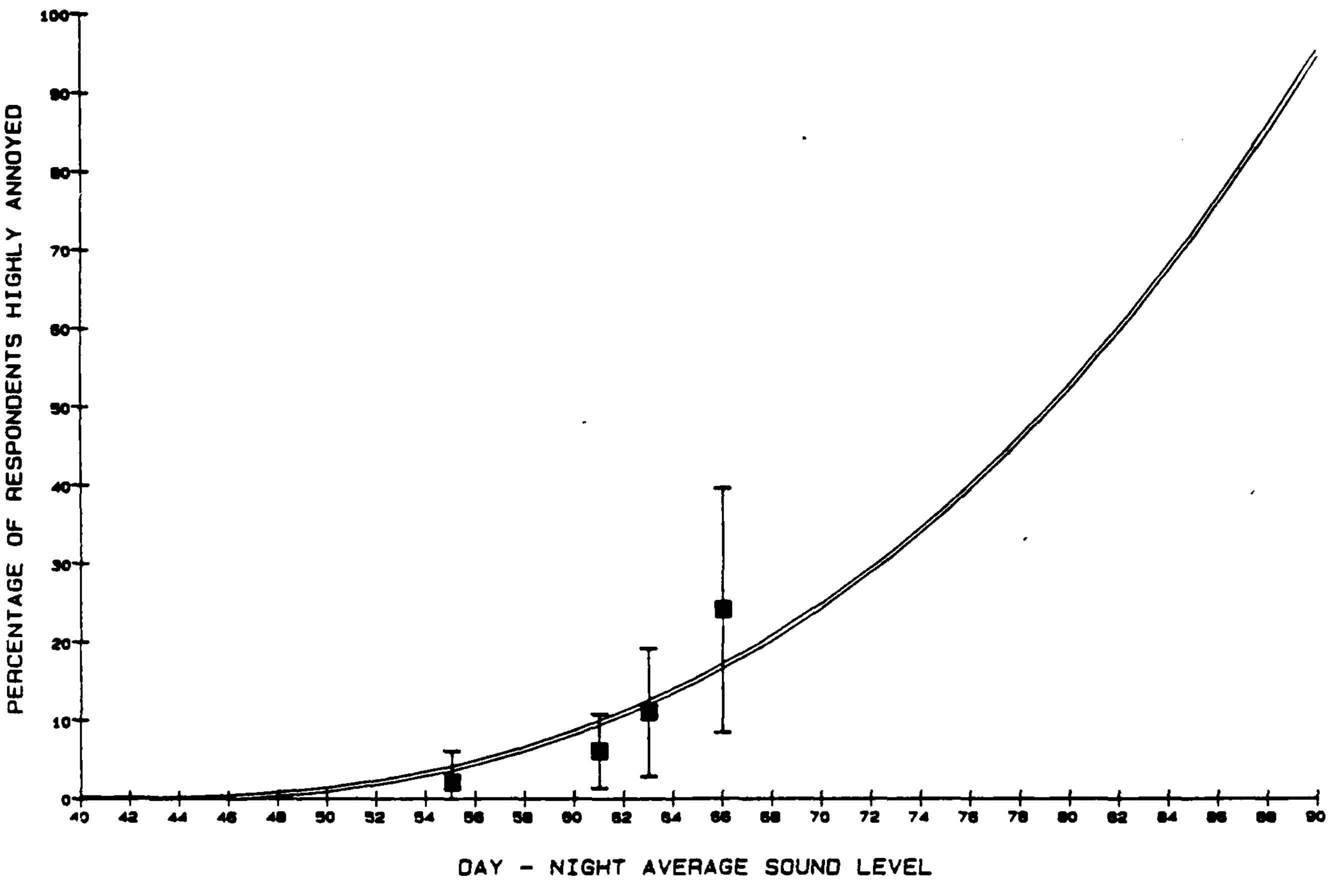


Figure 4-7: Relationship of Data from Decatur Airport Study to 1978 Synthesis Curve.

### 4.1.7 British Railroad (Fields and Walker, 1982; 1399 Interviews)

Fields and Walker conducted an attitudinal survey of railroad noise in Great Britain. They made more than 2000 noise measurements at 403 locations in units of 24-h $L_{eq}$, NNI, CNEL, and $L_{dn}$. Personal interviews were conducted with 45 to 220 respondents per site.

The authors tabulated percentages of respondents highly annoyed to a direct question (Questionnaire item 17b) worded as follows: "Does the noise of trains bother or annoy you: (1) Very Much, (2) Moderately, (3) A Little, or (4) Not At All." Respondents describing themselves as "Very Much" annoyed by train noise were considered to be highly annoyed for current purposes. This criterion of high annoyance slightly underestimates the prevalence of annoyance with respect to the 27% - 29% adopted for the 12 clustering surveys of the original synthesis.

Figure 4-8 shows 95% confidence intervals for the British Railroad data. The data points lie considerably below the original synthesis curve.

### 4.1.8 Swedish Railroad (Sorensen and Hammar, 1983; 1125 Interviews)

Sorensen and Hammar report an investigation performed during 1978-1980 of reactions to railroad train noise in areas surrounding the cities of Malmo and Stockholm. The authors interviewed 50 to 100 subjects at each of 15 sites. Noise was measured in units of 24-h $L_{eq}$ for each passing train. The conversion from the reported units of $L_{eq}$ to $L_{dn}$ was performed as described for the Rylander (1977) survey.

The data used in the present analysis are found in Figure 1 of Sorensen and Hammar (1983). Since the data were not tabulated, a grid was overlaid on Sorensen and Hammar's Figure 1 to estimate values of pairs of noise exposure levels and percentages of highly annoyed respondents.

Sorensen and Hammar did not report the labels of response categories used for eliciting annoyance judgments. They did, however, claim close similarity of annoyance measurement techniques with an earlier survey (Rylander et al., 1980) which used 4 named response categories: (1) Not Annoyed, (2) A Little Annoyed, (3) Rather Annoyed, and (4) Very Annoyed. Using the "Very Annoyed" category as the criterion of high annoyance only slightly underestimates the prevalence of annoyance with respect to the 27% - 29% adopted for the 12 clustering surveys of the original synthesis.

Figure 4-9 shows 95% confidence intervals for the 15 data points from this study. The points are generally in good agreement with the 1978 dosage-effect relationship.

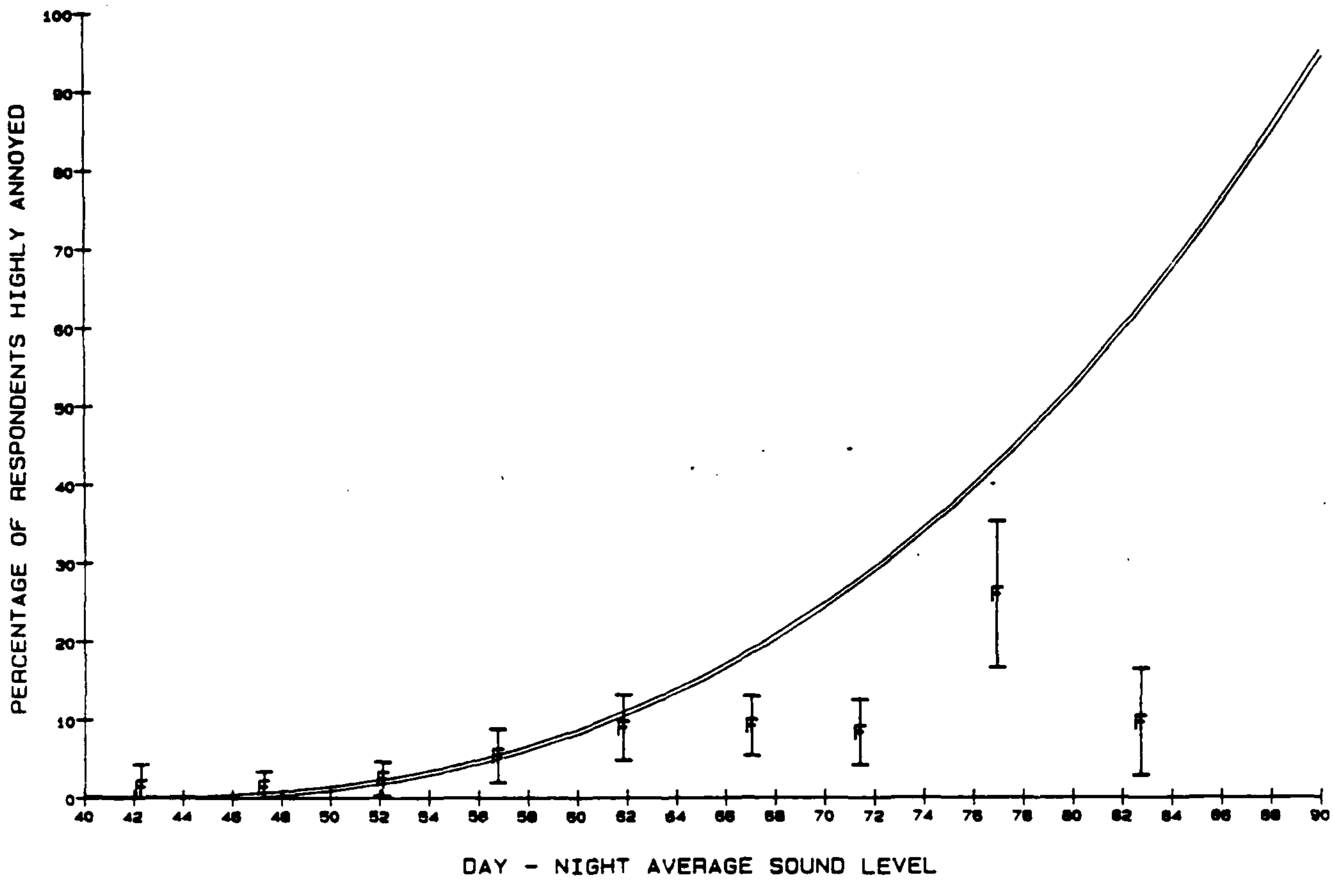


Figure 4-8: Relationship of Data from British Railroad Study to 1978 Synthesis Curve.

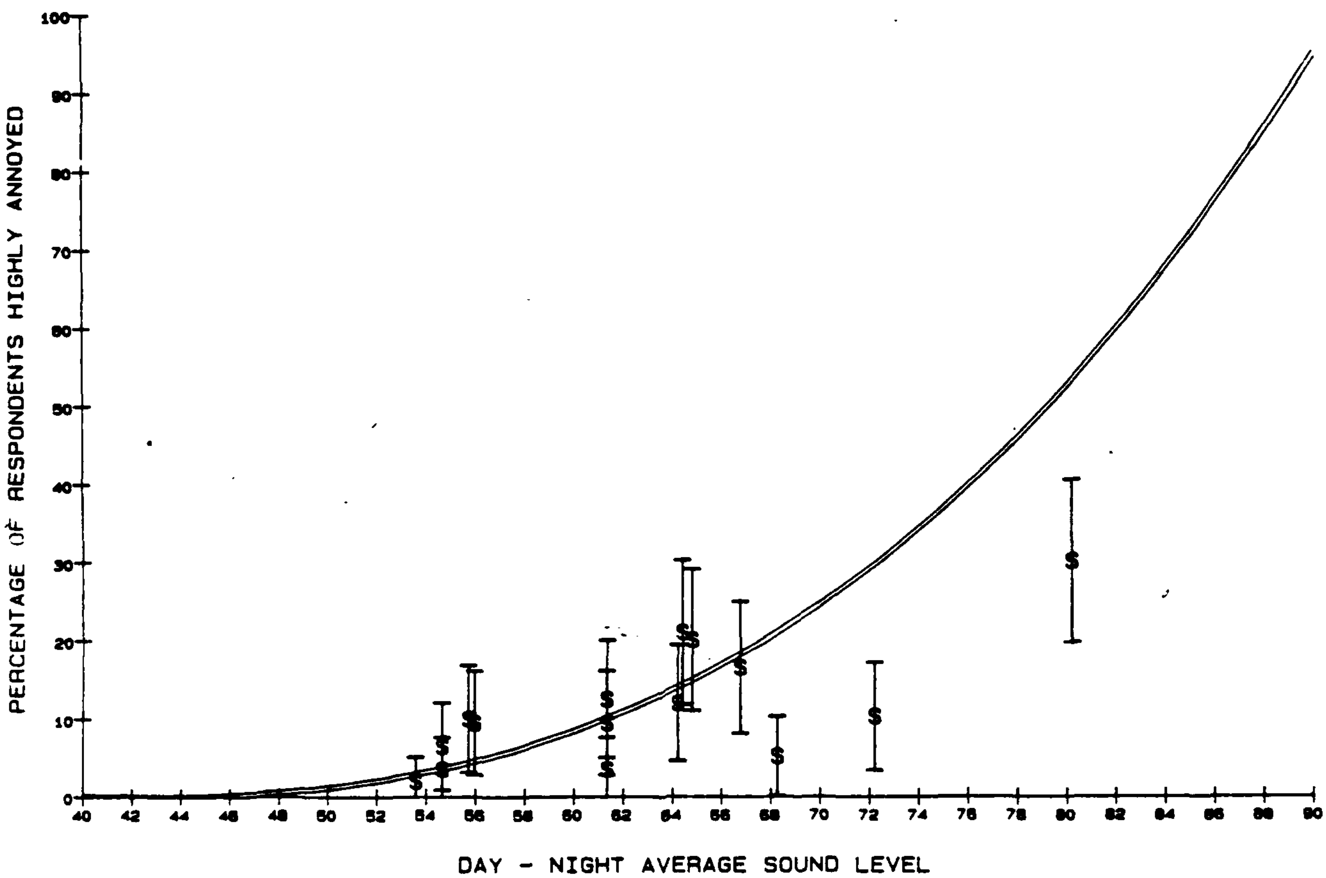


Figure 4-9: Relationship of Data from Swedish Railroad Study to 1978 Synthesis Curve.

#### 4.1.9 U.S. Airbase (Borsky, 1985; 874 Interviews)

Personal interviews were conducted with 27 to 45 respondents per site at 25 sites near 7 U.S. Air Force bases. Borsky used automatic equipment to measure exposure in units of $L_{dn}$ for approximately 10 days per site. A threshold of 65 dB(A) was used for these measurements. It is unclear how levels of exposure lower than this threshold value were estimated.

The data used in the present analysis[3] are based on a questionnaire item that asked "How much does noise from aircraft disturb, bother, or annoy you?" Respondents selected a response category from an "opinion thermometer" composed of 10 gradations with named end points, as follows:

"Not at all 0 1 2 3 4 5 6 7 8 9 Extremely"

Respondents were considered highly annoyed for present purposes if they selected categories 7, 8, or 9 (30% of the response scale).

Figure 4-10 shows the 95% confidence intervals calculated for the 25 sites. The data points cluster around or somewhat higher than the 1978 dosage-effect relationship.

#### 4.1.10 Westchester County Airport (Fidell et al., 1985; 1465 Interviews)

Fidell et al. report a social survey of the annoyance of aircraft noise at 4 sites around Westchester County Airport. Both personal and telephone interviews were conducted twice with samples of 100 to 250 respondents per site. Noise measurements were made by automatic equipment at multiple microphone locations within each site for a week prior to interviewing, and were reported in units of $L_{dn}$.

Table 6 of Fidell et al. (1985) summarizes the percentage of respondents highly annoyed and measured noise levels. Questionnaire Item 4 asked respondents "And how about this past (season of year): have you been bothered or annoyed by noise from airplanes while you've been at home during these months?" Respondents were allowed to choose one of the following categories: (1) Not At All Annoyed, (2) Slightly Annoyed, (3) Moderately Annoyed, (4) Very Annoyed, or (5) Extremely Annoyed. Respondents describing themselves as either "Very" or "Extremely" annoyed were considered highly annoyed for current purposes. This definition of high annoyance includes 40% of the response scale, overestimating the percentage highly annoyed by the preferred definition (27%-29% of the response scale) of the 1978 synthesis.

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[3]Data from this unpublished survey were provided by Dr. C. Stanley Harris of the Armstrong Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base.

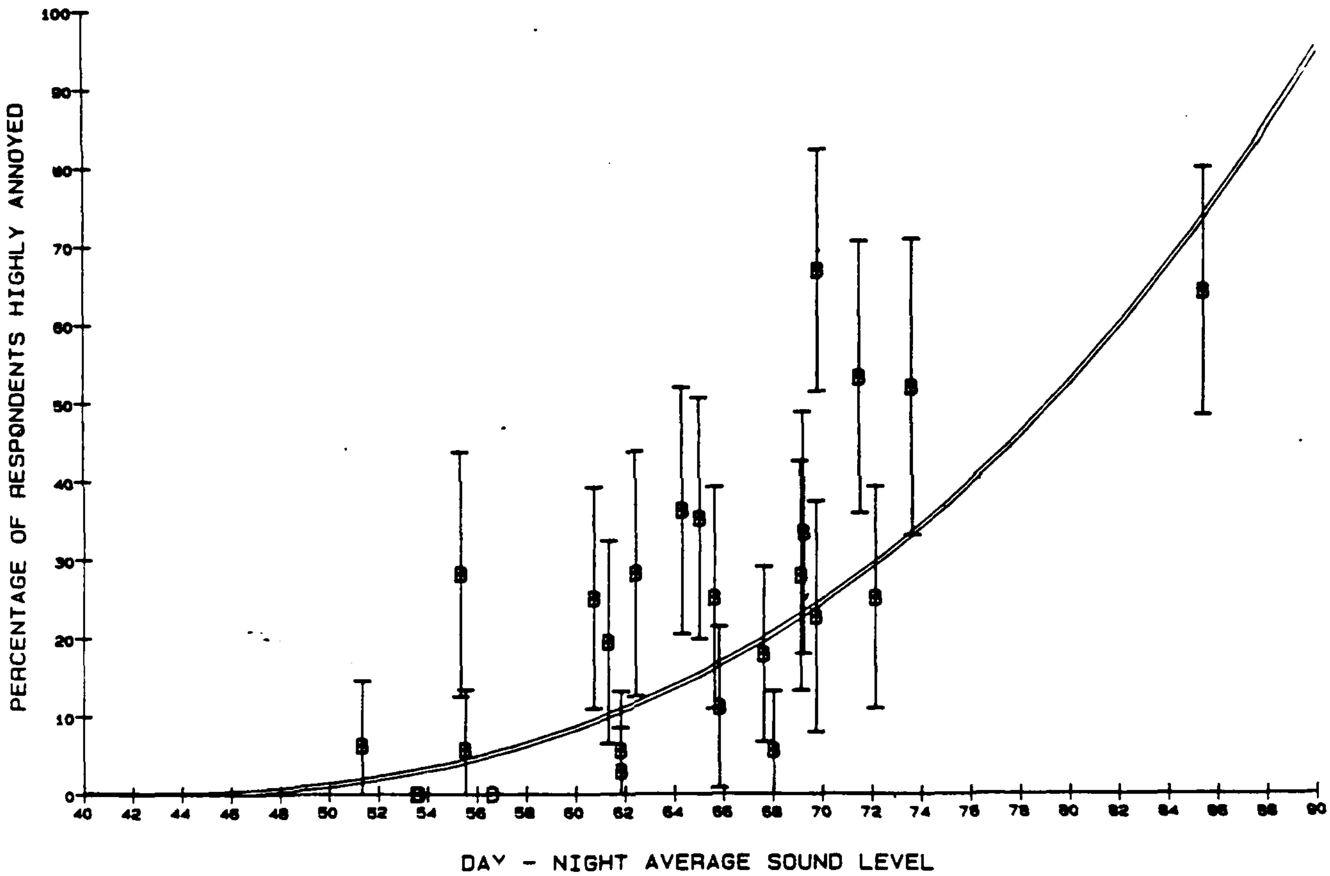


Figure 4-10: Relationship of Data from U.S. Airbase Study to 1978 Synthesis Curve.

Figure 4-11 presents the 95% confidence intervals for the 8 data points reported by Fidell et al. in relation to the dose-response curve generated by Schultz (1978). Most of the data points lie above the 1978 relationship.

### 4.1.11 Danish Railroad (Andersen et al., 1982, 615 Interviews)

Andersen et al. report a survey conducted near 7 Danish railways with traffic volumes ranging from 30 to 300 trains per 24-h. Numbers of respondents ranged from 1 to 55 at each of 26 sites. Noise measurements were reported by Andersen et al. in units of $L_{eq}$ and were converted to $L_{dn}$ by using the method described for the Rylander (1977) survey.

Andersen et al. directly asked respondents "Does railway noise annoy [you]?" Respondents indicated that they were (1) Strongly Annoyed, (2) Somewhat Annoyed, (3) Slightly Annoyed, (4) Very Little Annoyed, or (5) Not Annoyed At All. Respondents rating themselves as "Strongly Annoyed" were considered to be highly annoyed for present purposes. This represents 20% of the response scale, slightly underestimating high annoyance as defined by the 27-29% criteria.

A grid was overlaid on Figure 1 of Andersen et al. (1982) to estimate values of pairs of noise exposure levels and percentages of highly annoyed respondents.

Figure 4-12 shows 95% confidence intervals for the 26 data points from this study.

### 4.1.12 Other Studies

Data from the following studies (constituting the clustering and 4 addenda studies considered by Schultz, 1978) are included in the present analysis as well. The reader is referred to Schultz (1978) for a detailed explanation of the treatment of the data of these studies.

- French Aircraft (Alexandre and Josse, 1970)
- Second Heathrow Airport (MIL Research, 1971)
- First Heathrow Airport (McKennell,1963)
- London Traffic (Langdon, 1976)
- Munich Airport (Rohrman, et al., 1974)
- Paris Street (Aubree et al., 1971)
- French Rail (Aubree, 1975)
- Swedish Aircraft (Rylander et al., 1972)

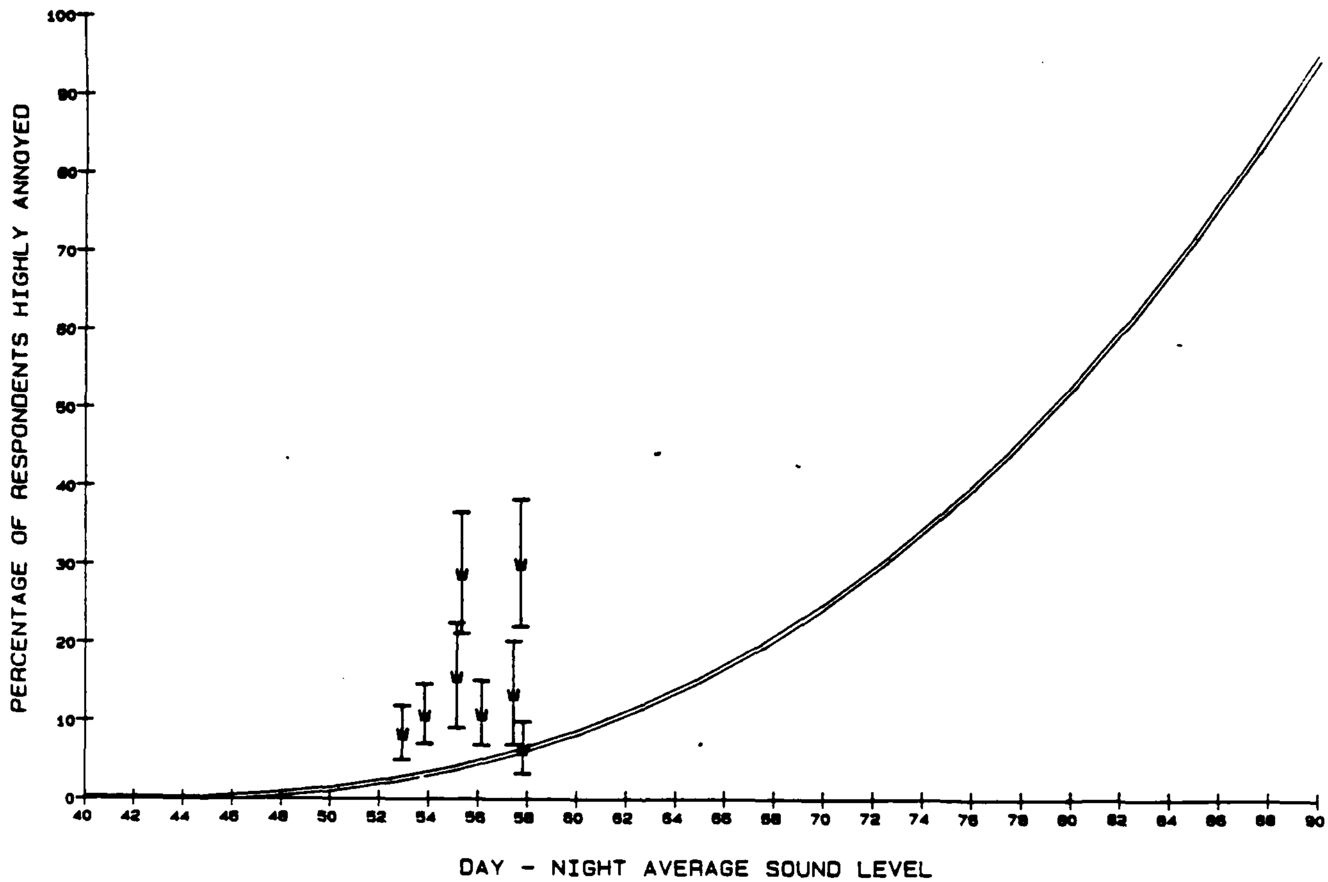


Figure 4-11: Relationship of Data from Westchester Airport Study to 1978 Synthesis Curve.

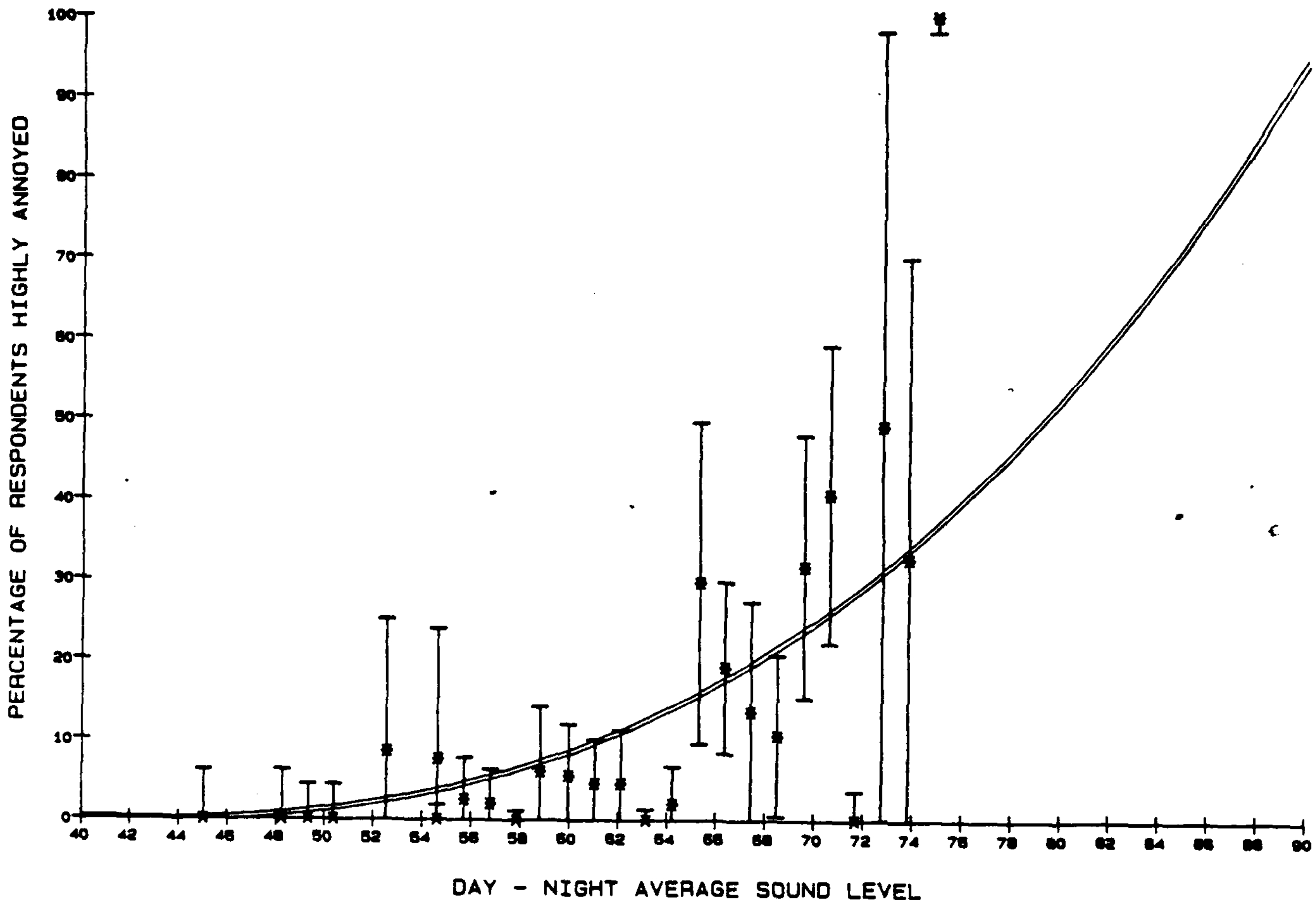


Figure 4-12: Relationship of Data from the Danish Railroad Study to 1978 Synthesis Curve.

- Swiss Road (Grandjean et al., 1975)
- Swiss Aircraft (Grandjean et al., 1973)
- USA 24 Site (Fidell, 1978)
- Los Angeles Airport (LAX 2 SITE) (Fidell and Jones, 1975)
- Antwerp Street (Myncke et al., 1977)
- Brussels Street (Myncke et al., 1977)
- Canadian Road (Hall and Taylor, 1977)
- Danish Street (Relster, 1975)

# 5. Derivation of Fitting Functions

Characterization of the data set developed in the previous chapter can be accomplished in several ways. This chapter derives fitting functions based on alternative analyses of subsets of the raw and transformed data.

## 5.1 Fitting Functions for Raw Data

The studies described in the previous chapter (plus the 4 addenda studies from Schultz (1978) yielded a total of 292 data points. Figure 5-1 combines the data from the individual studies described above into a single plot, along with the 161 data points from the clustering surveys of Schultz (1978). A least squares quadratic fit to the data points is also shown.

The equation of the quadratic fitting function is:

$$\%HA = .0360 L_{dn}^2 - 3.2701 L_{dn} + 79.1393 \qquad (5\text{–}1)$$

The quadratic fit accounts for 45.5% of the variance in the data points. Since the best fitting (least squares criterion) cubic relationship accounts for less than 1% more variance, and in the absence of any theoretical imperative in favor of either one, the quadratic is preferred over the cubic fit for reasons of parsimony.

Figure 5-2 compares the third-order polynomial function Schultz chose to fit the data of the 1978 synthesis with a second-order fitting function for all 453 data points. As can be seen, a quadratic fit to the new data points is several decibels higher (about 4 dB higher at an $L_{dn}$ value of 57.5 dB, and about 1.5 dB higher at an $L_{dn}$ value of 70 dB).

Figure 5-3 compares the 1978 dosage-effect relationship with (1) the (unconstrained) least squares quadratic fitting function shown in the previous figures and (2) with quadratic least squares fits to the upper and lower boundaries of the 95% confidence intervals for all data points. Note that the 1978 relationship lies within these limits over virtually all of its range.

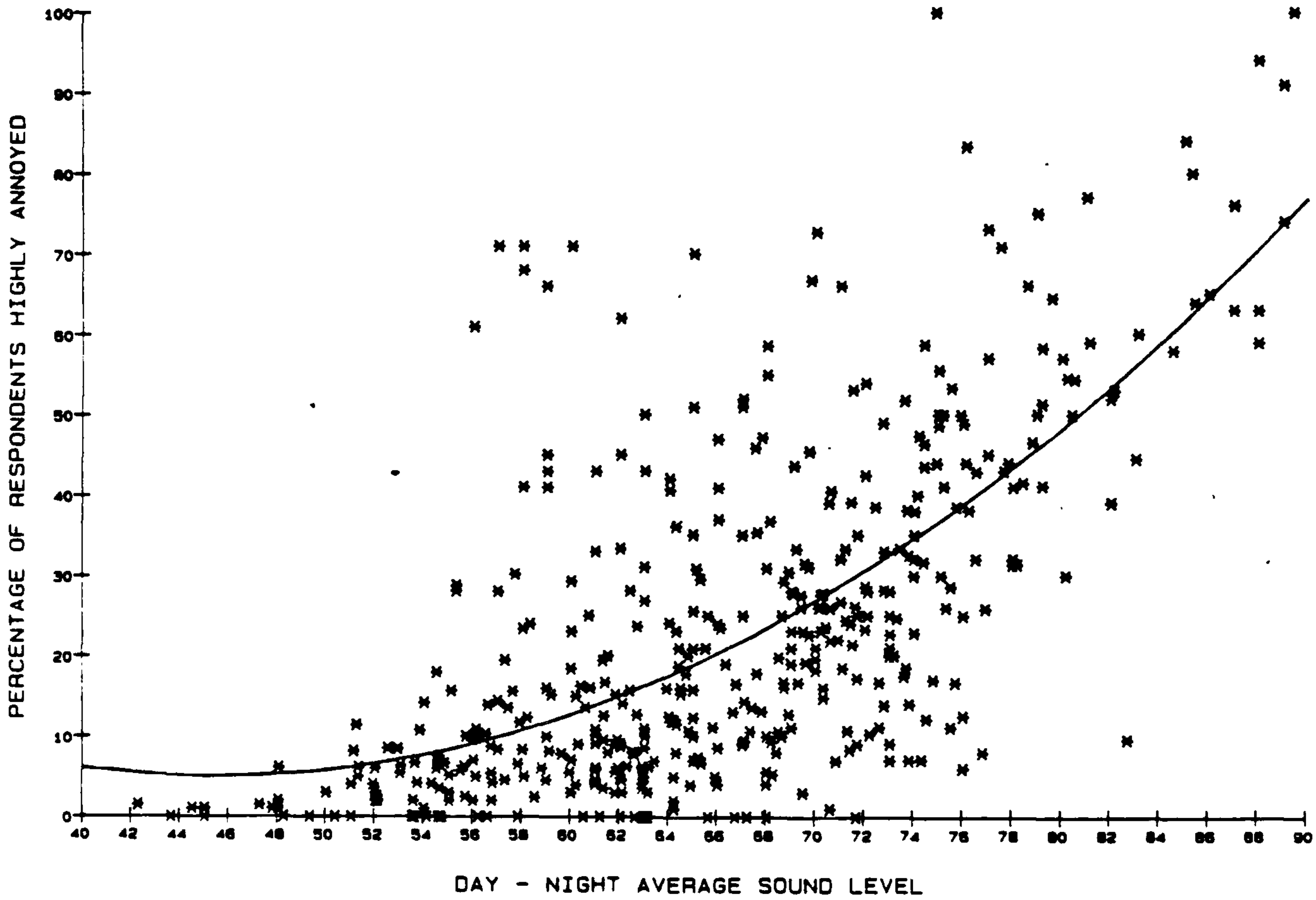


Figure 5-1: Quadratic Fit to All 453 Data Points.

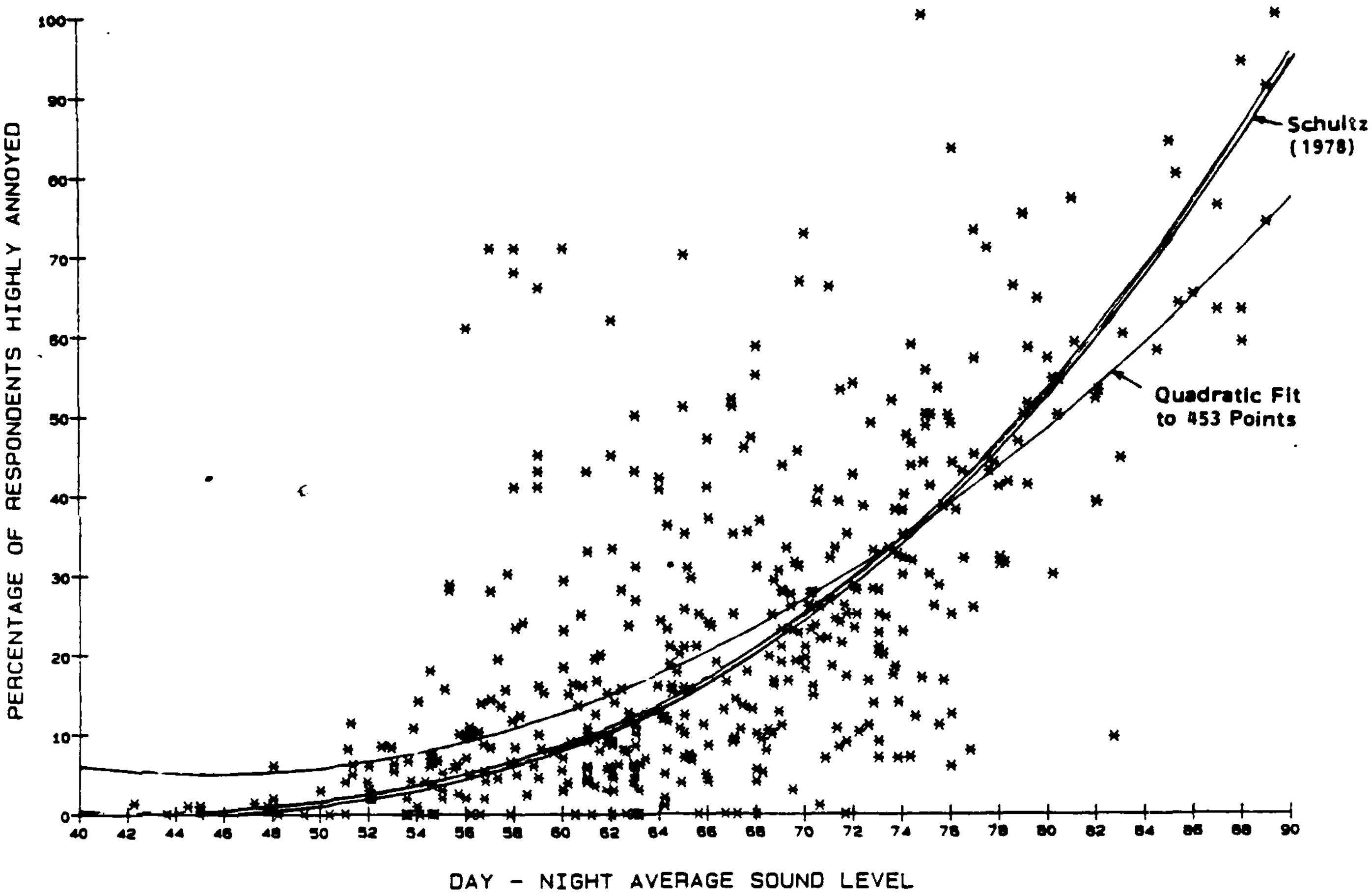


Figure 5-2: Comparison of 1978 3rd Order Polynomial Fitting Function with Quadratic Fit to 453 Data Points.

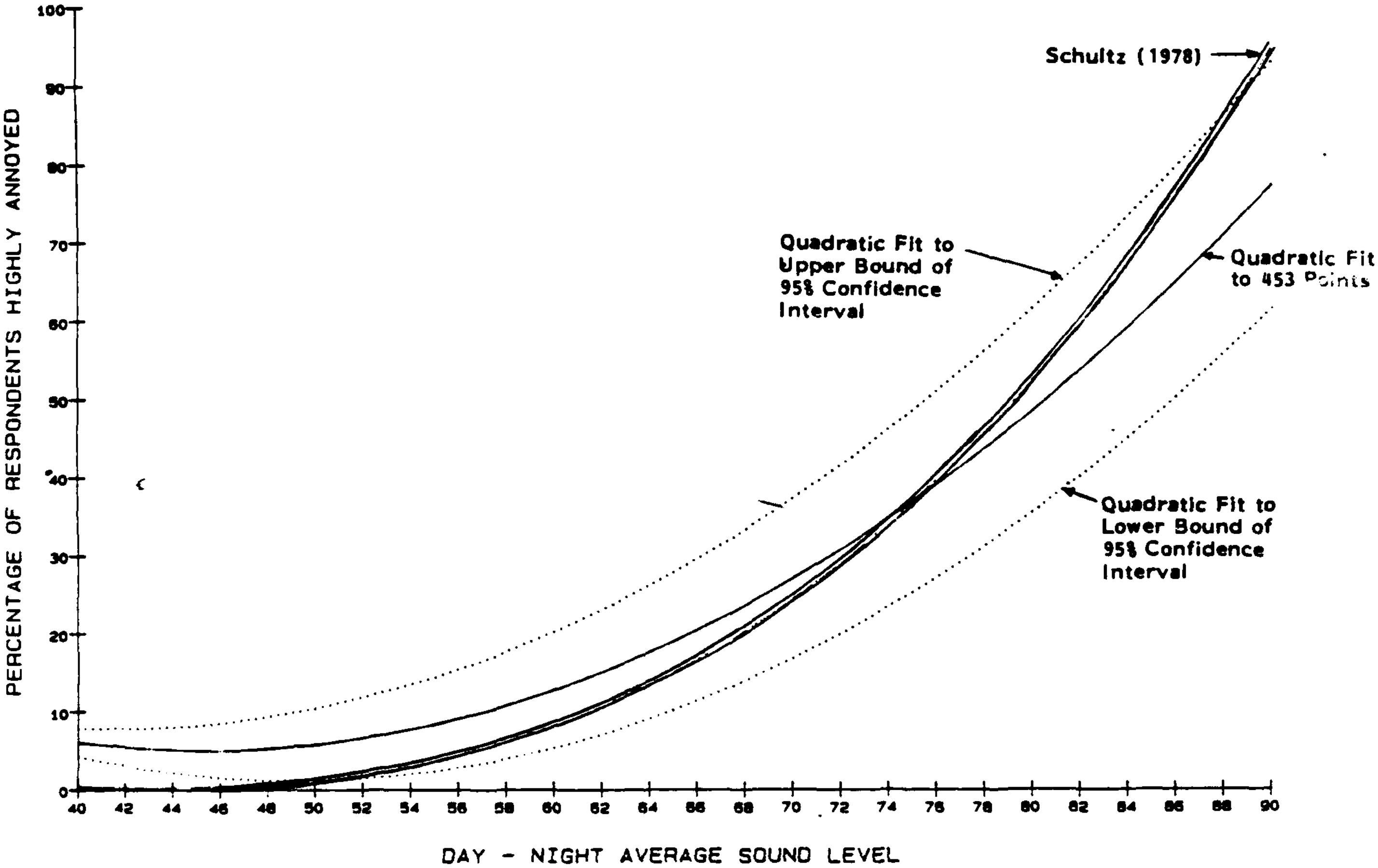


Figure 5-3: Comparison of Third-Order Polynomial and Quadratic Fitting Functions.

## 5.2 Exclusion of Data Points Lacking Positive Correlation between Noise Exposure and Annoyance

An alternative analysis of the present data excludes data from surveys which do not exhibit a significant correlation between noise exposure and annoyance. Table 5-1 shows the correlation coefficients and associated probabilities that observed correlations are significantly different from zero for all of the surveys. The 6 studies (containing 53 data points) that are excluded from this alternative analysis are indicated by an "X" in the last column.

Figure 5-4 shows only minor differences between least squares quadratic fits to the sets of 453[4] data points and the 400[5] data points from surveys in which only significant positive correlations are observed between exposure and annoyance.

### 5.2.1 Fits to Transformed Data

Probit and logit transforms were applied to the data of studies with correlations between exposure and annoyance significantly greater than zero. The former transform represents the annoyance data as normal deviates, while the latter represents the annoyance data as the natural logarithm of the ratio of the probability of high annoyance to its complement. Figure 5-5 shows only minor differences between least squares fits to the raw and transformed data sets.

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[4]Consisting of 29 data sets since 2 of the studies have more than 1 transportation noise source.

[5]Consisting of 23 data sets.

**Table 5-1: Correlations of Noise Source and Annoyance Response.**

| Study Name | Type of Study | Pearson r | r squared | Number of data points | Probability Level |
|---|---|---|---|---|---|
| LAX 2 Site | C | na | na | 2 | na |
| French Aircraft | C | 0.976 | 0.953 | 6 | 0.001 |
| Paris Street | C | 0.972 | 0.946 | 8 | 0.001 |
| French Rail | C | 0.964 | 0.929 | 5 | 0.010 |
| 2nd Heathrow Aircraft | C | 0.945 | 0.894 | 20 | 0.001 |
| Swiss Aircraft | C | 0.940 | 0.884 | 12 | 0.001 |
| Swiss Road | C | 0.923 | 0.853 | 6 | 0.010 |
| Orange County Airport | NEW | 0.908 | 0.826 | 12 | 0.001 |
| Decatur Airport | NEW | 0.894 | 0.799 | 4 | x |
| Munich Aircraft | C | 0.871 | 0.759 | 27 | 0.001 |
| 1st Heathrow Aircraft | C | 0.855 | 0.730 | 10 | 0.010 |
| Hall Traffic Only | NEW | 0.852 | 0.727 | 12 | 0.001 |
| London Traffic | C | 0.806 | 0.650 | 24 | 0.001 |
| Brussels Street | ADD | 0.801 | 0.642 | 23 | 0.001 |

NOTE:
C = Considered by Schultz (1978) to be "clustering"
ADD = Included in addendum of Schultz (1978)
NEW = Surveys published since 1978
x = Correlation not significantly different from zero at $p<.05$
na = Not applicable

**Table 5-1: continued.**

| Study Name | Type of Study | Pearson r | r squared | Number of data points | Probability Level |
|---|---|---|---|---|---|
| British Railroad | NEW | 0.777 | 0.603 | 11 | 0.010 |
| Danish Street | ADD | 0.760 | 0.578 | 28 | 0.001 |
| Canadian Traffic | ADD | 0.740 | 0.552 | 14 | 0.010 |
| Swedish Aircraft | C | 0.738 | 0.545 | 17 | 0.001 |
| U.S. Airbase | NEW | 0.735 | 0.541 | 25 | 0.001 |
| USA 24 Site Traffic | C | 0.708 | 0.500 | 24 | 0.001 |
| Swedish Railroad | NEW | 0.704 | 0.496 | 15 | 0.010 |
| Danish Railroad | NEW | 0.659 | 0.434 | 26 | 0.001 |
| Australian Aircraft | NEW | 0.649 | 0.422 | 42 | 0.001 |
| Antwerp Street | ADD | 0.637 | 0.406 | 31 | 0.001 |
| Hall Aircraft Only | NEW | 0.586 | 0.343 | 9 | x |
| Rylander Traffic Only | NEW | 0.556 | 0.309 | 6 | x |
| Rylander Tramway Only | NEW | 0.454 | 0.206 | 6 | x |
| Westchester Airport | NEW | 0.246 | 0.061 | 8 | x |
| Burbank Airport | NEW | -0.142 | 0.020 | 20 | x |

NOTE:
C = Considered by Schultz (1978) to be "clustering"
ADD = Included in addendum of Schultz (1978)
NEW = Surveys published since 1978
x = not significant at $p<.05$

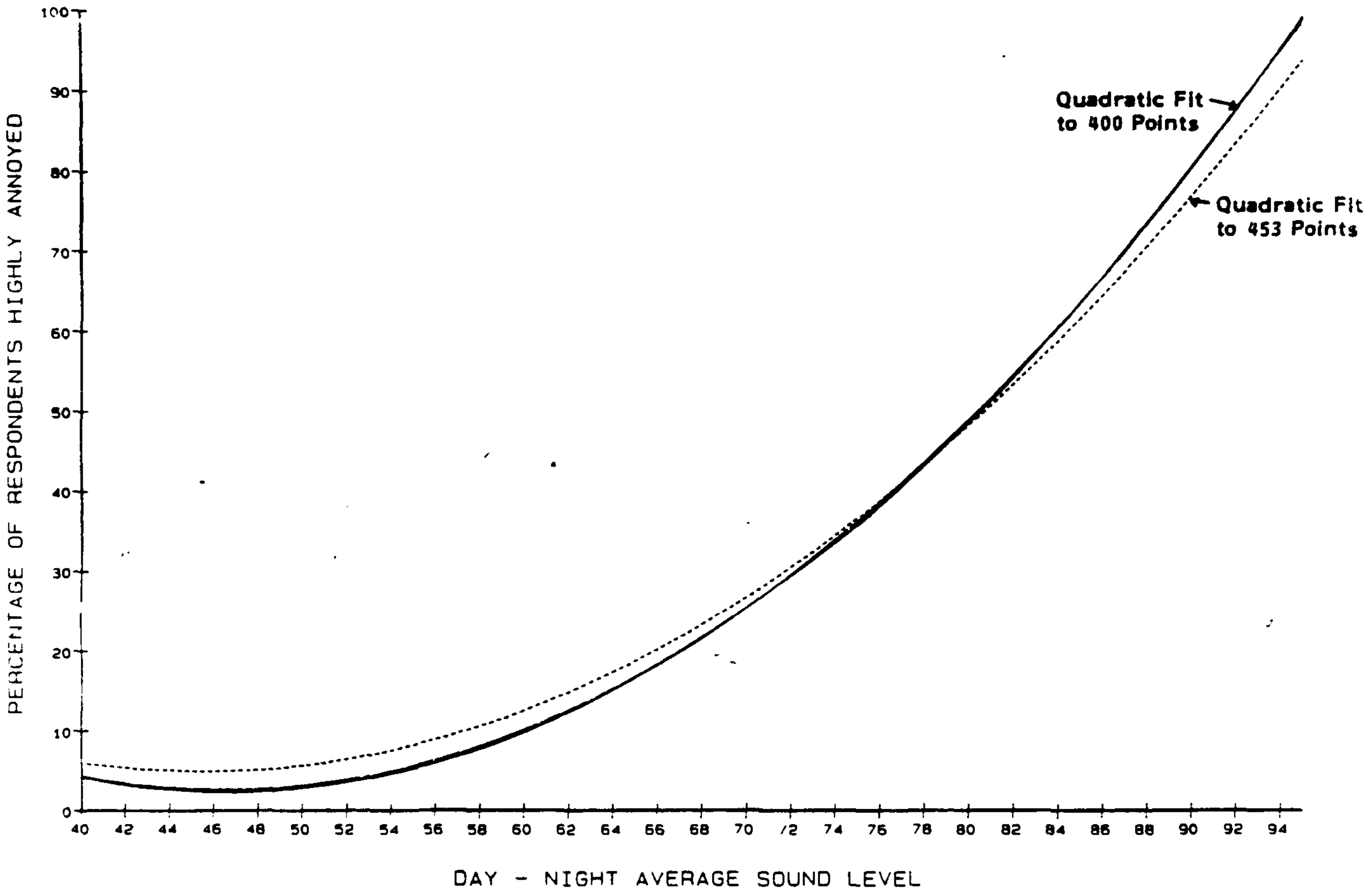


Figure 5-4: Comparison of Quadratic Fits for 453 and 400 points.

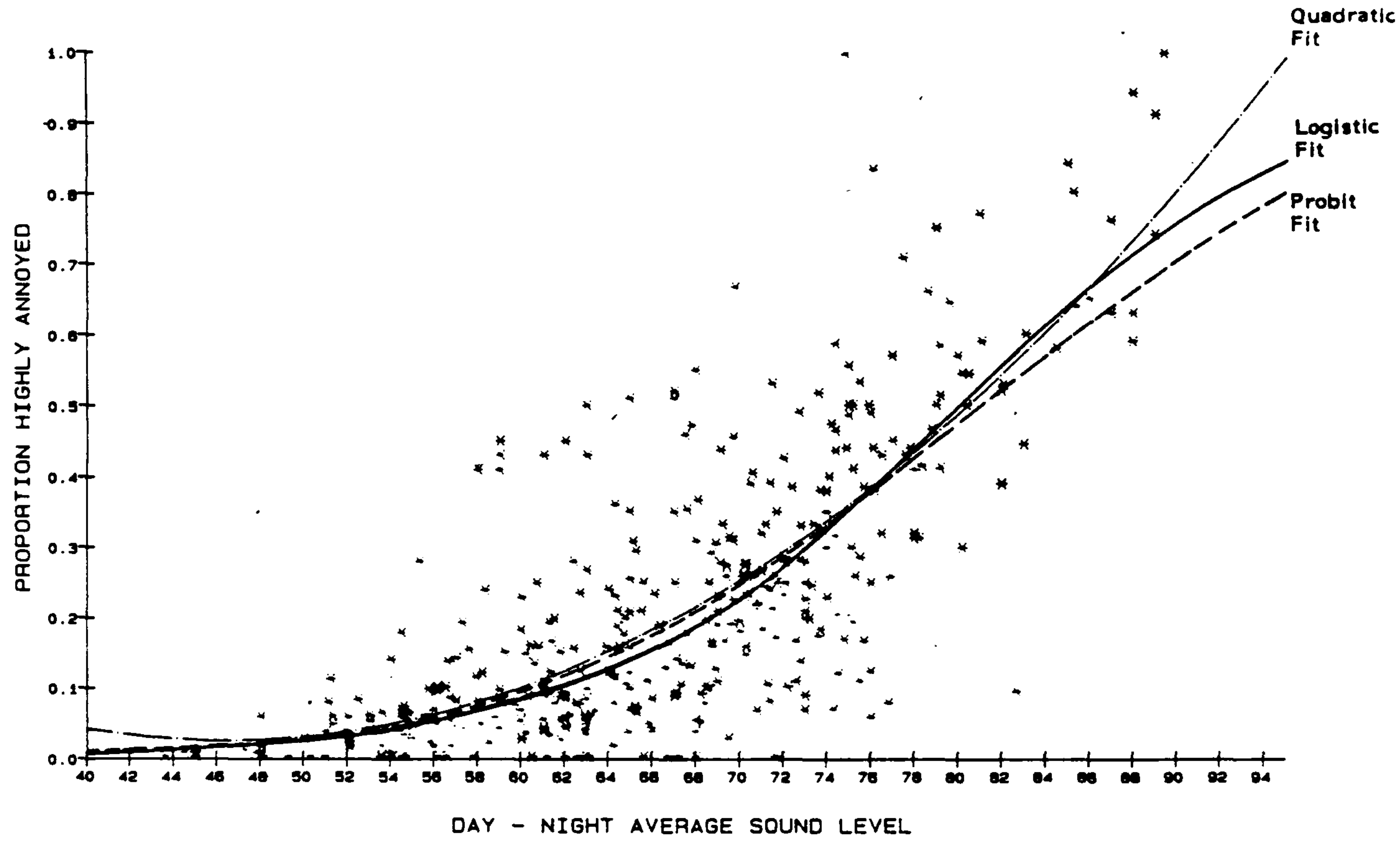


Figure 5-5: Comparison of Fits to Raw and Transformed Data.

# 6. Discussion

The information on which both the 1978 and the newly-derived dosage-effect relationships are based is not error-free. Indeed, there is uncertainty in quantification of both the dependent and independent variables of the dosage-effect relationship. Influences of errors of several types on the relationship are discussed in the following sections of this chapter.

## 6.1 Bias Errors in Definitions of High Annoyance

One obvious influence on the shape of the fitting function is the definition adopted for high annoyance in each of the data sets. Table 6-1 compares the percentages of the response alternatives included in the definition of "High Annoyance" in the 11 studies described in the previous chapter. On average, self-reports of annoyance in the upper 31.4% of the response alternatives in these studies were considered to meet criteria for "High Annoyance." This figure is slightly higher than the 27-29% average for the original clustering surveys on which the 1978 dosage-effect relationship is based. About half (45.5%) of the data points underestimate "High Annoyance" by 5%, while 54.5% of the data points overestimate "High Annoyance" by 10.3%.

Even these figures do not suggest the extent to which the dosage-effect relationship is sensitive to the definition of high annoyance in separate surveys. Because the present data set of 453 points is composed of a relatively large number of surveys each contributing a relatively small number of data points, changing the definition of high annoyance for any one survey produces only a small change in the dosage-effect relationship. For example, changing the definition of high annoyance adopted for the Burbank Airport data points from 40% of the response scale to 30% of the response scale as shown in Figure 6-1 changes the quadratic curve fit hardly at all.

## 6.2 Uncertainty in Measurements of Percentages of Respondents Highly Annoyed

Table 6-2 displays the sizes of the average estimated 95% confidence intervals for percentages of highly annoyed respondents for each of the 29 data sets. When published reports contained sufficient information, these estimates were made by calculating confidence intervals for each interviewing site and averaging them within studies. When the published reports

**Table 6-1:** Percentage of Response Alternatives Considered "Highly Annoying" in Surveys Not Considered in 1978 Synthesis.

| ***Comparison of Percentages*** | | | |
|---|---|---|---|
| *Survey* | *% of Response Scale Considered "Highly Annoying"* | *Percentage of Total Data Points* | *Percentage of New Data Points* |
| Australian Aircraft | 20% | 9.3% | 21.4% |
| Aircraft/Traffic | 40% | 4.6% | 10.7% |
| Burbank Airport | 40% | 4.4% | 10.2% |
| Orange County Airport | 40% | 2.7% | 6.1% |
| Tramway/Traffic | 25% | 2.7% | 6.1% |
| Decatur Airport | 40% | 0.9% | 2.0% |
| British Railroad | 25% | 2.4% | 5.6% |
| Swedish Railroad | 25% | 3.3% | 7.7% |
| U.S. Airbase | 30% | 5.5% | 12.8% |
| Westchester Airport | 40% | 1.8% | 4.1% |
| Danish Railroad | 20% | 5.7% | 13.3% |

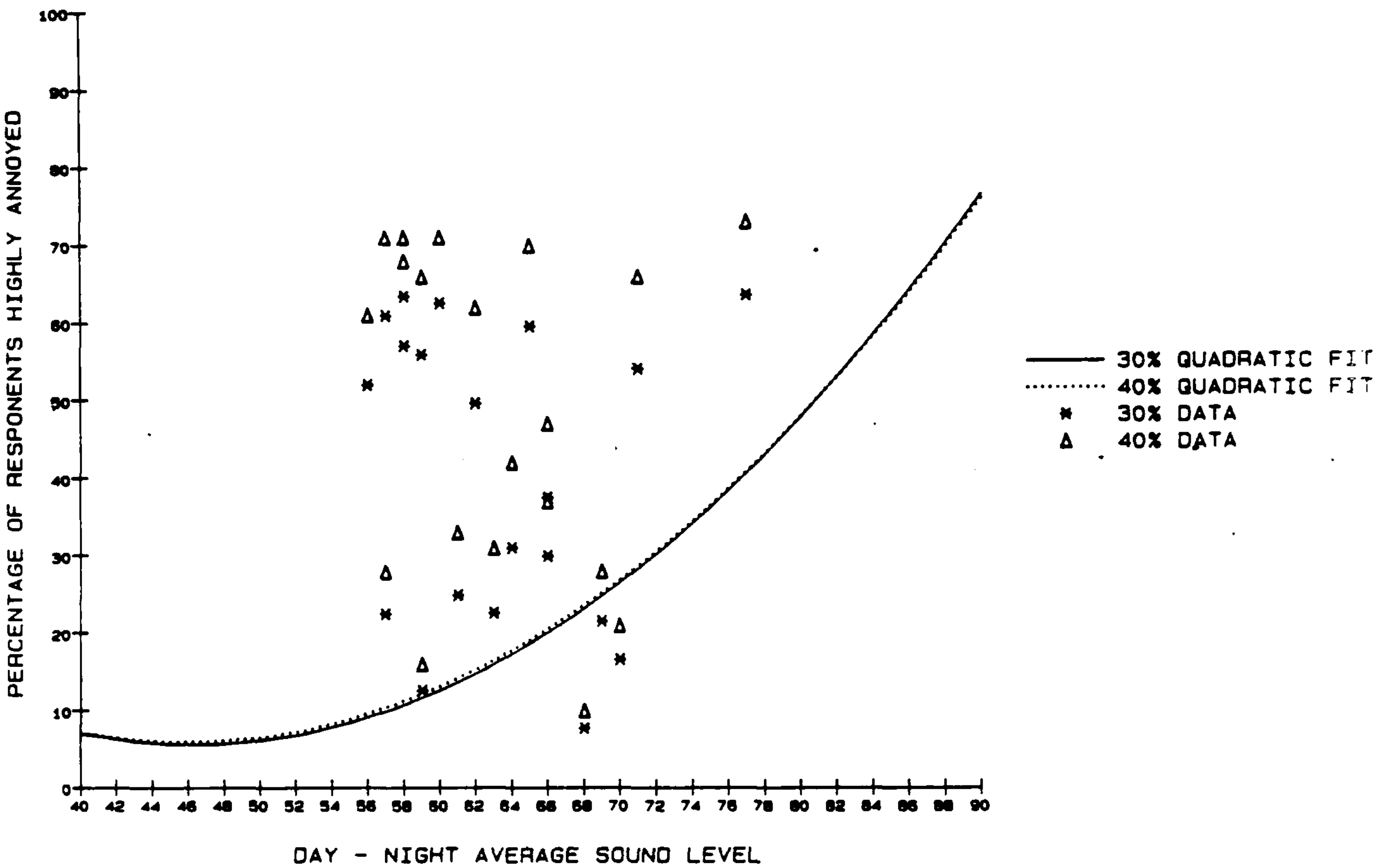


Figure 6-1: Effect of Changing Definition of High Annoyance for Burbank Data.

indicated only total numbers of respondents and interviewing sites, the estimates were made by by assuming equal numbers of respondents per site. As can be seen in Table 6-2, there is considerable uncertainty in some of the survey data about percentages of respondents highly annoyed.

The average width of the estimated 95% confidence intervals of the 29 studies is 16.5%. Given that the slope of the 1978 dosage-effect relationship is about 2 to 3% highly annoyed per decibel of noise exposure through much of its range, the uncertainty in the original survey data corresponds to a change in noise exposure of nearly an order of magnitude. Since this uncertainty represents the fundamental level of precision of measurement on the ordinate of the dosage-effect relationship, it is unproductive to seek explanations for smaller differences among potential fitting functions for these data.

## 6.3 Errors in Estimating Noise Exposure

A more difficult matter to address is uncertainty in reported measurements of noise exposure. Few of the studies reviewed provide sufficient detail to permit estimation of confidence intervals for such measurements. In general, the number of microphone locations, duration of measurement, calibration of measurements against other information, and homogeneity of exposure across interviewing sites are not extensively reported.

One exception is the measurements made at Burbank Airport. In this case, noise measurements were made at 5 locations within each interviewing site for a full week prior to interviewing, and the obtained measurements were calibrated against noise exposure gradients derived from aircraft noise contouring software. Even in this case, however, exposure varied by about ± 2.5 dB within interviewing sites. This figure is probably close to the greatest practically achievable precision of physical measurement. Thus, the position of any fitting function developed for this data set probably cannot withstand any closer scrutiny of its relationship to the abscissa than ± 3 dB.

Table 6-2: 95% Confidence Intervals for Determinations of Percentages of Respondents Highly Annoyed.

| *Rank Ordering of Studies by Average Estimated Confidence Intervals* | |
|---|---|
| *Width of 95% Confidence Interval (%)* | *Study* |
| 7.1 | Swiss Aircraft (Grandjean et al., 1973) |
| 7.2 | Traffic/Tramway (Traffic only, Rylander, 1977) |
| 7.4 | Second Heathrow Airport (MIL Research, 1971) |
| 7.5 | British Rail (Fields and Walker, 1982) |
| 7.6 | French Aircraft (Alexandre, 1970) |
| 9.0 | Swiss Road (Grandjean et al., 1973) |
| 10.9 | First Heathrow Airport (McKennell, 1963) |
| 10.9 | Westchester Airport (Fidell et al., 1985) |
| 11.3 | Burbank Airport (Fidell et al., 1985) |
| 11.4 | Traffic/Tramway (Tramway only, Rylander, 1977) |
| 12.3 | Orange County Airport (Fidell et al., 1985) |
| 12.5 | Los Angeles Airport (Fidell and Jones, 1975) |
| 13.5 | Swedish Rail (Sorensen and Hammar, 1983) |
| 14.3 | Australian Aircraft (Hede and Bullen, 1982) |
| 14.5 | Brussels Street (Myncke et al., 1977) |
| 14.8 | USA 24 Site (Fidell, 1978) |
| 16.3 | Antwerp Street (Myncke et al., 1977) |
| 16.3 | Decatur Airport (Schomer, 1983) |

Table 6-2: 95% Confidence Intervals for Determinations of Percentages of Respondents Highly Annoyed (continued).

| *Rank Ordering of Studies by Average Estimated Confidence Intervals* | |
|---|---|
| *Width of 95% Confidence Intervals (%)* | *Study* |
| 17.3 | French Rail (Aubree, 1975) |
| 18.7 | Paris Street (Aubree et al., 1971) |
| 20.2 | Danish Railroad (Andersen et al., 1982) |
| 22.1 | Traffic/Aircraft Comparison (Traffic only, Hall et al., 1977 |
| 22.4 | Canadian Road (Hall and Taylor, 1977) |
| 23.4 | U.S. Airbase (Borsky, 1985) |
| 23.9 | Danish Street (Relster, 1975) |
| 24.4 | London Traffic (Langdon, 1976) |
| 29.5 | Traffic/Aircraft Comparison (Aircraft only, Hall et al., 1977) |
| 32.0 | Munich Airport (Rohrman et al., 1974) |
| 40.3 | Swedish Aircraft (Rylander et al., 1972) |

## 6.4 Reliability of Dosage-Effect Relationship

One implication of these errors (roughly ± 3 dB on the abscissa and ± 8% on the ordinate) in the data set is that the relatively small differences between the current dosage-effect relationship and the one synthesized in 1978 should not be over interpreted. The differences are minor ones that could be attributed as persuasively to errors of measurement of various sorts as to substantive effects. In fact, over the range of exposure values of practical interest to environmental planners, a linear fit could provide a reasonable approximation to a dosage-response relationship.

Another implication is that more sophisticated curve fitting procedures are required if one wishes to deal explicitly with uncertainty on both axes of the relationship. For example, if the goal were to weight the salience of each data point by the magnitude of its likely errors of both physical and psychological measurement, a dosage-effect relationship with a rather different shape might well emerge.

Another limitation of both the 1978 polynomial approximation and the current quadratic fitting function is that they are both simply convenient data fitting functions lacking physical meaning. Both functions are positively accelerated within the range of DNL values of interest to environmental planners, and both are nonmonotonic: care is necessary to avoid using these relationships outside their intended ranges. Common sense strongly suggests that, in reality, the function relating exposure to annoyance must be a sigmoid asymptotic to values of the prevalence of annoyance in the vicinity of 0 and 100%. The least squares fits to the logit and probit-transformed data have this advantage, as does an exponential fit derived in a companion report (Fidell and Green, 1989).

# 7. Conclusions

The addition of 292 new points to the 161 data points from which Schultz (1978) synthesized a quantitative dosage-effect relationship between transportation noise and annoyance affected the relationship very little. The new relationship summarizes opinions of respondents collected in approximately 40,000 interviews in 27 studies (29 data sets). As such, it represents the most comprehensive basis available for predicting the prevalence of annoyance associated with noise exposure.

The relationship is, however, a completely atheoretical one that deals only with the prevalence of apparent annoyance. Its application is limited in the same ways as the original relationship synthesized by Schultz (1978). In particular, the relationship does not address the potential confounding of self-reported annoyance with response bias, a matter addressed in another Air Force sponsored ongoing project.

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# Appendix A
# Tables of Raw Data for Individual Studies Described in Chapter 4

**Table A-1:** Data from French Aircraft Survey (Alexandre, 1970).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 52.1 | 2.0 |
| 58.1 | 5.0 |
| 64.1 | 12.0 |
| 70.1 | 26.0 |
| 76.1 | 44.0 |
| 82.1 | 53.0 |

**Table A-2:** Data from Paris Street Survey (Aubree et al., 1971).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 63.9 | 16.0 |
| 66.6 | 13.0 |
| 69.4 | 27.5 |
| 72.1 | 28.0 |
| 74.9 | 44.0 |
| 77.6 | 43.0 |
| 80.4 | 50.0 |
| 83.1 | 60.0 |

Table A-3: Data from French Rail Survey (Aubree, 1975).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 62.0 | 9.1 |
| 66.0 | 8.6 |
| 70.0 | 19.6 |
| 74.0 | 22.9 |
| 78.0 | 31.3 |

Table A-4: Data from Swiss Road Survey (Grandjean et al., 1973).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 55.0 | 5.1 |
| 58.5 | 2.4 |
| 62.0 | 4.8 |
| 65.0 | 12.3 |
| 68.5 | 19.8 |
| 72.0 | 23.3 |

Table A-5: Data from USA 24 Site Survey (Fidell, 1978).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 51.1 | 8.1 |
| 53.6 | 6.7 |
| 54.3 | 4.1 |
| 54.8 | 6.7 |
| 56.1 | 9.8 |
| 56.1 | 10.3 |
| 56.6 | 13.9 |
| 57.6 | 15.6 |
| 59.1 | 8.1 |
| 60.2 | 3.9 |
| 60.8 | 16.0 |
| 61.9 | 9.5 |
| 62.3 | 6.3 |
| 62.4 | 15.7 |
| 62.7 | 12.7 |
| 62.7 | 23.6 |
| 64.3 | 23.1 |
| 64.5 | 15.3 |
| 67.3 | 10.6 |
| 68.9 | 30.5 |
| 69.0 | 11.1 |
| 70.6 | 21.9 |
| 71.7 | 25.0 |
| 72.8 | 28.2 |

Table A-6: Data from London Traffic Survey (Langdon, 1976).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 64.3 | 11.6 |
| 65.1 | 30.8 |
| 68.0 | 30.9 |
| 69.1 | 43.7 |
| 69.7 | 31.0 |
| 69.7 | 45.5 |
| 70.2 | 27.6 |
| 70.3 | 27.7 |
| 70.4 | 23.6 |
| 70.6 | 25.9 |
| 70.9 | 22.0 |
| 73.4 | 33.3 |
| 74.2 | 47.4 |
| 74.4 | 58.7 |
| 75.2 | 41.1 |
| 75.9 | 50.0 |
| 78.4 | 41.5 |
| 78.6 | 66.0 |
| 78.8 | 46.6 |
| 79.2 | 58.3 |
| 79.2 | 51.4 |
| 79.6 | 64.5 |
| 80.2 | 54.5 |
| 80.5 | 54.4 |

Table A-7: Data from Second Heathrow Airport Survey (MIL Research, 1971).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 45.0 | 1.0 |
| 48.0 | 1.0 |
| 52.0 | 3.0 |
| 56.0 | 2.0 |
| 60.0 | 3.0 |
| 65.0 | 7.0 |
| 69.0 | 19.0 |
| 73.0 | 25.0 |
| 78.0 | 32.0 |
| 82.0 | 39.0 |
| 45.0 | 1.0 |
| 48.0 | 2.0 |
| 52.0 | 3.0 |
| 56.0 | 7.0 |
| 60.0 | 7.0 |
| 65.0 | 10.0 |
| 69.0 | 21.0 |
| 73.0 | 28.0 |
| 78.0 | 32.0 |
| 82.0 | 39.0 |

Table A-8: Data from First Heathrow Airport Survey (McKennell, 1963).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 48.0 | 6.1 |
| 54.0 | 14.2 |
| 60.0 | 18.4 |
| 53.0 | 6.3 |
| 59.0 | 9.9 |
| 65.0 | 20.9 |
| 65.0 | 15.8 |
| 70.0 | 18.2 |
| 71.0 | 32.0 |
| 76.0 | 48.9 |

Table A-9: Data from Hall Aircraft/Traffic Comparison Survey (Aircraft Only, Hall et al., 1977).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 58.0 | 23.4 |
| 60.0 | 29.3 |
| 62.0 | 33.3 |
| 64.0 | 40.7 |
| 66.0 | 40.9 |
| 68.0 | 58.6 |
| 70.0 | 72.7 |
| 72.0 | 53.9 |
| 74.0 | 32.0 |

Table A-10: Data from Munich Airport Survey (Rohrman et al., 1974).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 63.0 | 5.0 |
| 63.0 | 10.0 |
| 67.0 | 9.0 |
| 68.0 | 0.0 |
| 73.0 | 7.0 |
| 73.0 | 21.0 |
| 74.0 | 30.0 |
| 74.0 | 38.0 |
| 75.0 | 50.0 |
| 75.0 | 50.0 |
| 76.0 | 25.0 |
| 77.0 | 57.0 |
| 78.0 | 41.0 |
| 79.0 | 50.0 |
| 79.0 | 75.0 |
| 79.0 | 75.0 |
| 80.0 | 57.0 |
| 81.0 | 77.0 |
| 85.0 | 84.0 |
| 86.0 | 65.0 |
| 87.0 | 63.0 |

Table A-10. continued.

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 87.0 | 76.0 |
| 88.0 | 59.0 |
| 88.0 | 63.0 |
| 88.0 | 94.0 |
| 89.0 | 74.0 |
| 89.0 | 91.0 |

**Table A-11:** Data from Swedish Aircraft Survey (Rylander et al., 1972).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 44.5 | 1.0 |
| 50.0 | 3.0 |
| 52.0 | 6.0 |
| 54.0 | 1.0 |
| 54.5 | 6.0 |
| 54.5 | 7.0 |
| 54.5 | 18.0 |
| 60.0 | 3.0 |
| 60.0 | 23.0 |
| 60.5 | 0.0 |
| 61.0 | 4.0 |
| 62.5 | 8.0 |
| 65.5 | 21.0 |
| 66.0 | 4.0 |
| 70.5 | 39.0 |
| 74.0 | 35.0 |
| 76.5 | 32.0 |

**Table A-12:** Data from U.S. Airbase Survey (Borsky, 1985).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 51.3 | 6.2 |
| 53.5 | 0.0 |
| 53.6 | 0.0 |
| 55.3 | 28.1 |
| 55.5 | 5.7 |
| 56.6 | 0.0 |
| 60.7 | 25.0 |
| 61.3 | 19.4 |
| 61.8 | 5.6 |
| 61.8 | 2.9 |
| 62.4 | 28.1 |
| 64.3 | 36.1 |
| 65.0 | 35.1 |
| 65.6 | 25.0 |
| 65.8 | 11.1 |
| 67.6 | 17.8 |
| 68.0 | 5.6 |
| 69.1 | 27.8 |

Table A-12. continued.

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 69.2 | 33.3 |
| 69.7 | 22.6 |
| 69.8 | 66.7 |
| 71.5 | 53.1 |
| 72.1 | 25.0 |
| 73.6 | 51.8 |
| 85.4 | 63.9 |

Table A-13: Data from Burbank Aircraft Survey (Fidell et al., 1985).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 56.0 | 61.0 |
| 57.0 | 71.0 |
| 57.0 | 28.0 |
| 58.0 | 68.0 |
| 58.0 | 71.0 |
| 59.0 | 16.0 |
| 59.0 | 66.0 |
| 60.0 | 71.0 |
| 61.0 | 33.0 |
| 62.0 | 62.0 |
| 63.0 | 31.0 |
| 64.0 | 42.0 |
| 65.0 | 70.0 |
| 66.0 | 47.0 |
| 66.0 | 37.0 |
| 68.0 | 10.0 |
| 69.0 | 28.0 |
| 70.0 | 21.0 |
| 71.0 | 66.0 |
| 77.0 | 73.0 |

Table A-14: Data from Orange County Aircraft Survey (Fidell et al., 1985).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 58.0 | 41.0 |
| 59.0 | 41.0 |
| 59.0 | 43.0 |
| 59.0 | 45.0 |
| 61.0 | 43.0 |
| 62.0 | 45.0 |
| 63.0 | 50.0 |
| 63.0 | 43.0 |
| 65.0 | 51.0 |
| 67.0 | 51.0 |
| 67.0 | 52.0 |
| 68.0 | 55.0 |

Table A-15: Data from Westchester Airport Survey (Fidell et al., 1985).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 52.9 | 8.4 |
| 53.8 | 10.8 |
| 55.1 | 15.7 |
| 55.3 | 28.8 |
| 56.1 | 10.9 |
| 57.4 | 13.5 |
| 57.7 | 30.1 |
| 57.7 | 6.5 |

**Table A-16:** Data from Hall Aircraft/Traffic Comparison Survey (Traffic Only, Hall et al., 1977).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 53.0 | 5.4 |
| 55.0 | 3.0 |
| 57.0 | 8.3 |
| 59.0 | 4.5 |
| 61.0 | 5.7 |
| 63.0 | 8.6 |
| 65.0 | 25.6 |
| 67.0 | 35.0 |
| 69.0 | 23.1 |
| 71.0 | 26.7 |
| 73.0 | 22.7 |
| 75.0 | 48.6 |

**Table A-17:** Data from Decatur Airport Survey (Schomer, 1983).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 55.0 | 2.0 |
| 61.0 | 6.0 |
| 63.0 | 11.0 |
| 66.0 | 24.0 |

Table A-18: Data from Rylander Tramway/Traffic Survey (Tramway Only, Rylander, 1977).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 64.2 | 5.0 |
| 62.1 | 3.0 |
| 69.5 | 23.0 |
| 64.2 | 1.0 |
| 71.7 | 9.0 |
| 62.1 | 14.0 |

Table A-19: Data from British Railroad Survey (Fields and Walker, 1982).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 29.2 | 0.0 |
| 37.3 | 0.0 |
| 42.3 | 1.5 |
| 47.3 | 1.4 |
| 52.1 | 2.5 |
| 56.7 | 5.4 |
| 61.8 | 8.9 |
| 67.0 | 9.1 |
| 71.4 | 8.3 |
| 76.9 | 25.9 |
| 82.7 | 9.6 |

Table A-20: Data from Danish Street Survey (Relster, 1975).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 51.0 | 0.0 |
| 51.0 | 4.0 |
| 51.2 | 11.4 |
| 51.3 | 5.0 |
| 51.9 | 4.0 |
| 54.1 | 0.0 |
| 56.5 | 10.3 |
| 57.3 | 19.4 |
| 57.9 | 11.7 |
| 58.3 | 24.0 |
| 61.0 | 9.1 |
| 61.0 | 10.2 |
| 61.4 | 16.7 |
| 61.5 | 8.0 |
| 67.8 | 47.2 |
| 68.1 | 36.7 |
| 70.8 | 6.9 |
| 71.2 | 24.5 |
| 71.2 | 33.3 |
| 71.4 | 24.0 |
| 71.7 | 35.0 |
| 73.2 | 20.0 |

**Table A-20. continued.**

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 73.7 | 38.1 |
| 74.1 | 40.0 |
| 74.4 | 46.6 |
| 74.4 | 43.6 |
| 75.1 | 30.0 |
| 76.1 | 83.3 |

Table A-21: Data from Canadian Road Survey (Hall and Taylor, 1977).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 57.3 | 4.5 |
| 63.0 | 0.0 |
| 61.9 | 6.0 |
| 64.3 | 8.0 |
| 68.0 | 4.0 |
| 68.4 | 8.0 |
| 69.4 | 26.0 |
| 76.0 | 6.0 |
| 75.3 | 26.0 |
| 74.8 | 17.0 |
| 76.0 | 12.5 |
| 76.8 | 8.0 |
| 83.0 | 44.5 |
| 84.5 | 58.0 |

Table A-22: Data from Brussels Street Survey (Myncke et al., 1977).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 66.7 | 0.0 |
| 69.3 | 16.7 |
| 64.7 | 17.7 |
| 70.2 | 26.1 |
| 76.2 | 38.1 |
| 64.9 | 3.9 |
| 75.5 | 53.3 |
| 79.2 | 41.2 |
| 65.3 | 6.7 |
| 65.6 | 0.0 |
| 72.4 | 38.5 |
| 61.5 | 20.0 |
| 71.6 | 26.1 |
| 75.7 | 16.7 |
| 70.2 | 23.1 |
| 68.7 | 16.1 |
| 77.8 | 44.0 |
| 72.0 | 28.6 |
| 68.6 | 10.0 |
| 77.5 | 70.8 |
| 62.6 | 0.0 |
| 70.3 | 14.8 |
| 62.9 | 5.9 |

Table A-23: Data from Australian Aircraft Survey (Hede and Bullen, 1982).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 53.7 | 4.2 |
| 54.7 | 0.0 |
| 55.6 | 6.3 |
| 56.2 | 0.0 |
| 56.7 | 8.8 |
| 56.8 | 4.2 |
| 57.0 | 14.4 |
| 58.0 | 8.3 |
| 58.2 | 12.3 |
| 59.2 | 15.2 |
| 59.6 | 7.8 |
| 60.2 | 15.0 |
| 60.4 | 16.3 |
| 60.5 | 0.0 |
| 60.6 | 13.6 |
| 61.0 | 4.4 |
| 61.0 | 10.8 |
| 61.2 | 0.0 |
| 61.8 | 15.2 |
| 62.6 | 7.8 |
| 62.9 | 3.6 |
| 62.9 | 4.2 |
| 62.9 | 6.3 |

Table A-23. continued.

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 63.0 | 26.8 |
| 63.2 | 6.3 |
| 64.0 | 12.5 |
| 64.0 | 24.1 |
| 64.4 | 18.8 |
| 65.2 | 7.1 |
| 65.9 | 5.0 |
| 66.1 | 23.4 |
| 67.5 | 45.9 |
| 67.6 | 35.4 |
| 68.2 | 9.3 |
| 68.7 | 16.7 |
| 68.7 | 29.2 |
| 68.9 | 12.8 |
| 71.1 | 18.5 |
| 71.4 | 39.1 |
| 71.5 | 21.4 |
| 72.0 | 42.5 |
| 73.3 | 24.7 |

Table A-24: Data from Swedish Railroad Survey (Sorensen and Hammar, 1983).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 53.6 | 2.0 |
| 54.6 | 3.5 |
| 54.6 | 6.5 |
| 56.0 | 9.5 |
| 55.7 | 10.0 |
| 61.3 | 3.5 |
| 61.3 | 12.5 |
| 61.3 | 9.5 |
| 64.2 | 12.0 |
| 64.4 | 21.0 |
| 64.8 | 20.0 |
| 66.8 | 16.5 |
| 68.3 | 5.3 |
| 72.2 | 10.3 |
| 80.2 | 30.0 |

Table A-25: Data from Los Angeles Airport Survey (Fidell and Jones, 1975).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 67.0 | 25.0 |
| 82.0 | 52.0 |

**Table A-26:** Data from Rylander Tramway/Traffic Survey (Traffic Only, Rylander, 1977).

| ***Day-Night Average Sound Level (dB)*** | ***Percentage of Respondents Highly Annoyed*** |
|---|---|
| 73.8 | 14.0 |
| 63.1 | 0.0 |
| 70.6 | 1.0 |
| 71.7 | 0.0 |
| 73.8 | 7.0 |
| 63.1 | 3.0 |

**Table A-27:** Data from Anderson Railroad Survey (Anderson et al., 1982).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 45.0 | 0.0 |
| 48.2 | 0.0 |
| 49.3 | 0.0 |
| 50.4 | 0.0 |
| 52.5 | 8.5 |
| 54.6 | 0.0 |
| 54.6 | 7.5 |
| 55.7 | 2.5 |
| 56.8 | 2.0 |
| 57.8 | 0.0 |
| 58.8 | 6.0 |
| 60.0 | 5.5 |
| 61.0 | 4.5 |
| 62.1 | 4.5 |
| 63.1 | 0.0 |
| 64.2 | 2.0 |
| 65.3 | 29.5 |
| 66.3 | 19.0 |
| 67.4 | 13.5 |
| 68.5 | 10.5 |

Table A-27. continued.

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 69.5 | 31.5 |
| 70.6 | 40.5 |
| 71.7 | 0.0 |
| 72.7 | 49.0 |
| 73.8 | 32.5 |
| 74.9 | 100.0 |

Table A-28: Data from Antwerp Street Survey (Myncke et al., 1977).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 62.0 | 0.0 |
| 62.2 | 8.7 |
| 63.4 | 6.9 |
| 64.8 | 10.7 |
| 65.2 | 7.4 |
| 67.1 | 14.3 |
| 67.1 | 9.4 |
| 67.2 | 0.0 |
| 67.8 | 13.1 |
| 69.5 | 3.0 |
| 69.6 | 19.2 |
| 70.3 | 16.0 |
| 71.3 | 10.7 |
| 71.7 | 17.2 |
| 72.6 | 11.1 |
| 72.6 | 16.7 |
| 72.8 | 13.9 |
| 73.0 | 9.1 |
| 73.0 | 20.0 |
| 73.6 | 17.5 |

Table A-28. continued.

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 73.7 | 18.5 |
| 74.3 | 7.1 |
| 74.4 | 31.7 |
| 74.5 | 12.2 |
| 75.0 | 55.6 |
| 75.2 | 50.0 |
| 75.5 | 28.6 |
| 75.5 | 11.1 |
| 75.7 | 38.5 |
| 76.5 | 42.9 |
| 78.2 | 31.3 |

Table A-29: Data from Swiss Aircraft Survey (Grandjean et al., 1973).

| *Day-Night Average Sound Level (dB)* | *Percentage of Respondents Highly Annoyed* |
|---|---|
| 43.6 | 0.0 |
| 47.8 | 1.0 |
| 52.0 | 2.0 |
| 56.1 | 5.0 |
| 60.3 | 9.0 |
| 64.5 | 16.0 |
| 68.6 | 25.0 |
| 72.8 | 33.0 |
| 77.0 | 45.0 |
| 81.1 | 59.0 |
| 85.3 | 80.0 |
| 89.4 | 100.0 |